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The Billion Pound Drop: The Blitz and Agglomeration Economics in London

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Abstract
This paper exploits locally exogenous variation in the location of bombs dropped during the Blitz to quantify the effect of density restrictions on agglomeration economies in London: an elite global city. Employing microgeographic data on office rents and employment, this analysis points to effects for London several multiples larger than the existing literature which primarily derives its results from secondary cities. In particular, doubling employment density raises rents by 25%. Consequently if the Blitz had not taken place, the resulting loss in agglomeration economies to present day London would cause total annual office rent revenues to fall by $4:5 billion { equivalent to 1:2% of London's annual GDP. These results illuminate the substantial impact of land-use regulations in one of the world's largest and most productive cities.

Key words: regulatory costs, office rents, agglomeration economies, London Blitz bombings.
JEL: R14; R33; R38

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1 Introduction

Cities are engines of economic growth. Scholars have long recognized that this enhanced productivity appears to be heavily dependent upon the built environment – particularly the scale and density of economic activity. However once cities' spatial structures have been established, they are difficult to modify. This sluggishness of change is understood to reflect the presence of so-called 'density frictions'. Although density frictions may arise from a variety of sources including the inherent durability of the building stock, in many if not most cities the primary density friction is thought to be regulation.

A common class of such regulations is density restrictions – particularly building height limits. Such restrictions may not necessarily reduce social welfare, as they may be a means to mitigate various externalities such as traffic congestion and incompatible land uses (Brueckner 2000). Density restrictions may also protect amenities and increase the quality of the built environment, implying a positive effect on land prices. However, many planning regulations limiting density have grown historically and do not adjust to changes in local demand (Cheshire 2009). Therefore regulatory hurdles pose perhaps the greatest obstacle to more compact urban growth (Cheshire & Sheppard 2002, Glaeser et al. 2005, Glaeser & Gottlieb 2009, Hilber & Vermeulen 2016). London, the city on which we focus this paper, is a particularly interesting case. Cheshire & Hilber (2008) show that London can be considered the world's most restrictive major office market – and far more restrictive than any market in the United States. Yet within London there are substantial local differences in land-use restrictions. For example, London's West End submarket is much more restrictive than the City of London or Canary Wharf, ostensibly due to its history and abundance of cultural amenities. Employment densities in the West End are consequently considerably lower than in London's other submarkets.

Density frictions in commercial real estate markets generally constrain employment densities, which implies that the potential to interact with other workers and benefit from agglomeration economies is less than if there were no frictions prohibiting firms from greater clustering. Agglomeration economies arise due to labour market pooling, input and output sharing, and knowledge spillovers (Marshall 1890), and appear to be highly dependent on the density of economic activities (Ciccone & Hall 1996, Rosenthal & Strange 2003, Ahlfeldt et al. 2016). These advantages seem to explain why rent for a unit of office space in elite global cities like London, New York, and Tokyo are several multiples above their corresponding national averages. As a global financial center, London is not only a major host to industries which greatly benefit from higher local densities, but also to some of the world's most innovative firms and people. In the presence of such potentially large agglomeration economies it has been suggested that governments should encourage rather than prohibit the clustering of firms within cities (Rossi-Hansberg 2004). At the very least, an understanding of the economic effects of density in these high productivity locations is essential to beginning the policy debate.

However, several endogeneity issues make identification of the economic effects of density challenging. Height constraints and density, for example, could be directly influenced by prices (see Hilber & Robert-Nicoud 2013). In this study we address this issue by using a quasi-experimental setting based on the Blitz bombings, which erased a substantial portion of London's building stock at the time.[1] We use the local concentration of the bombs dropped during the Blitz as an exogenous proxy for the permissiveness of present day local regulation. We demonstrate the validity of this proxy with suggestive evidence that planning applications are indeed less likely to be rejected and that buildings are taller in more heavily bombed areas. A concern with this methodology is that the location of bombings may not be completely random over space, and therefore may be correlated with centrality or local amenities. To address this concern, we present both anecdotal and rigorous statistical evidence that the locations of Blitz bombings were indeed random at our local scale of analysis.

Because higher densities increase the potential for agglomeration economies, we hypothesize that greater Blitz bomb densities should now be associated with higher productivity and higher land values. This is consonant with an emerging literature showing that within-city differences in agglomeration economies are an important determinant of various economic outcomes including; firm location choice (Arzaghi & Henderson 2008), land prices (Ahlfeldt et al. 2016), property prices (Cheshire & Dericks 2014), and rents (Koster et al. 2014), and that these effects appear to attenuate rapidly with distance. Furthermore, the capitalization of this enhanced productivity into local price differentials should be even greater for locations with tight supply constraints such

[1] For instance, it is estimated that a third of the buildings in the City of London were destroyed (Marriott 1989, p.66)

as London (Sivitanidou & Wheaton 1992, Rosenthal & Strange 2004). We then use the locally random Blitz bombings as an instrument for current employment density, thereby demonstrating the particularly strong effect that agglomeration economies within London have on office rents.

This paper makes a number of contributions to the literature on the economic effects of land use regulation and the measurement of agglomeration economies. While the economies of the developed world have ostensibly been liberalized over the past several decades, land use regulation has by contrast generally expanded and intensified (McLaughlin 2012). Although the current empirical literature on the economic effects of land use regulation focuses almost entirely on the housing market (see Hornbeck & Keniston 2017, Turner et al. 2014, Siodla 2015), such restrictions would seem much more important in the context of commercial property, whose high-rise office buildings dominate most CBDs.[2] Similar to only a few recent studies of agglomeration economies, we employ actual transactions of commercial office rents for individual buildings as our dependent variable.[3] Although using wage data is most common, office rents are arguably the best economic manifestation of agglomeration economies arising from service industries in urban areas (Drennan & Kelly 2011, p.488). We also compare our results derived from office rents with those from house prices – a commonly used proxy for commercial rents within the agglomeration economies literature – and show that this substitution may underestimate the true magnitude of the effects. Furthermore, we examine London exclusively, and at a microgeographic scale, thereby producing specific estimates for the level of agglomeration economies operative within the one of the world's largest and most productive cities. No previous research on agglomeration economies has utilized transactions-based commercial data at such a fine spatial scale and in a city of comparable size and sophistication to London. We also show that within London agglomeration economies seem to extend for some distance beyond the immediate location of firms (at least 1 km).

In addition, our results contribute to the still limited stream of research within the broader agglomeration literature that has employed exogenous sources of variation in employment density. However, unlike some previous research we are able to objectively demonstrate the conditional exogeneity of our instrument: Blitz bombings. We achieve this by adapting the industrial localization metric of Duranton & Overman (2005) to rigorously test for the spatial randomness

[2] As an illustration, of London's 10 tallest buildings only one is classified as residential.
[3] see for example Koster et al. (2014) and Liu et al. (2016)

of Blitz bomb strikes. Employing historical war damage as a source of exogenous variation has become increasingly common in empirical work addressing challenging econometric questions. For example, using wartime bombings as a proxy for economic shocks, Davis & Weinstein (2002), Brakman et al. (2004), and Bosker et al. (2007) show that enduring location-based natural advantages maintain the relative economic status *between* cities over the long-run. Whereas, akin to this study, Koster & Rouwendal (2012) and Redding & Sturm (2016) investigate the long-run impact of war damage *within* cities.

Our results point toward a strong and negative net effect of density frictions on office rents: a one standard deviation increase in bomb density leads to an increase in rents of about 8.5%. Additionally, we show that agglomeration economies are a key determinant of office rents in elite cities: the elasticity of rents with respect to agglomeration appears to be about 5 times as large as that commonly measured for wages, and half again to twice as large as previous estimates using rents primarily derived from regional and other secondary cities. Back-of-the-envelope calculations highlight the importance of density frictions: if the Blitz bombings had not taken place, employment density would be about 50% lower and the resulting loss in agglomeration economies would lower total revenues from office space in Greater London by about £4.5 billion per year, equivalent to 1.2% of Greater London's GDP or 39% of its average annual growth rate.[4]

This paper proceeds as follows. In Section 2, we summarize the expected effects and provide a background on the importance of density frictions and agglomeration economies in the London office market and discusses the London Blitz. Section 3 provides evidence that the Blitz bombings are (conditionally) random at our local scale of analysis, and correlates the location of bombings with current density restrictions. Section 4 introduces the data used and outlines the econometric framework. Section 5 discusses the results, followed by a sensitivity analysis – including substituting office rents with house prices in Section 6. Section 7 concludes.

[4] Average annual growth rate for Greater London 1999–2016 is 3.0%: sourced from ONS

2 Research context

2.1 Hypotheses

In this paper, we evaluate the effects of density frictions and agglomeration economies on transactions-based commercial and residential rents. What are the expected effects? Let us assume a production function $\Phi(\cdot)$, consisting of labour n, a public good z and the quality of the building q. The profit $\pi(x)$ per unit of commercial space at location x is then:

$$\pi(x) = \Phi(n(x), q(x, n(x)), z(x)) - w(x)n(x) - r(x), \tag{1}$$

where $w(x)$ is the wage paid to workers, and $r(x)$ are the rents per unit of commercial space. We assume a perfectly competitive market, so in equilibrium it holds that $\pi(x) = 0, \forall x$. The public good $z(x)$ is a production externality and depends on the number of workers in nearby locations. We expect that $\partial\pi(x)/\partial z(x) > 0$, so that firms are more productive in denser locations, which is in line with the extensive (empirical) literature on agglomeration economies. Based on the optimality conditions associated with (1) we assume that firms choose the optimal number of workers. However, density frictions may prohibit the firm to do so. Hence, following Borck (2016), $n(x) = \min(\bar{n}, n^*(x))$, with $\bar{n} \leq n^*(x)$.

We allow for the fact that the quality of buildings is some function of $n(x)$. It may be that $\partial q(x)/\partial\bar{n} < 0$ when density restrictions force construction firms to construct aesthetically more appealing buildings at lower densities, or prevent construction firms from demolishing attractive (historic) buildings. It might also be that $\partial q(x)/\partial\bar{n} > 0$, *i.e.* density frictions prohibit the construction of new buildings that have a higher quality (*e.g.* better air quality, more windows) and are not obsolete (Taubman & Rasche 1969, Bokhari & Geltner 2016)

The price per unit of commercial space is then given by $r(x) = \phi(n(x), q(x, n(x)), z(x)) - w(x)n(x)$. So, the presence of agglomeration economies leads to higher densities and higher land prices. We can write the full derivative of prices with respect to a change in $\bar{n}$ as:

$$\frac{\mathrm{d}r(x)}{\mathrm{d}\bar{n}} = \left(\frac{\partial r(x)}{\partial\bar{n}} + \frac{\partial r(x)}{\partial q(x)}\frac{\partial q(x)}{\partial\bar{n}}\right) + \left(\frac{\partial r(x)}{\partial w(x)}\frac{\partial w(x)}{\partial\bar{n}}\right) + \left(\frac{\partial r(x)}{\partial z(x)}\frac{\partial z(x)}{\partial\bar{n}}\right) \tag{2}$$

The first term on the right hand side in parentheses is the internal effect of density frictions, which represent the cost on how land is used and the quality of buildings that result from differences in density frictions (see Turner et al. 2014). For example, this may encompass the cost of inefficient building use, and the fact that firms cannot find buildings that host their optimal number of employees. Note that $\partial r(x)/\partial \bar{n} > 0$, implying that when density frictions are less pronounced, office rents will be higher. However, the sign of $\partial q(x)/\partial \bar{n}$ is indeterminate, because density frictions may both lead to higher or lower quality buildings.

The second term between parentheses is the effect of density frictions on wages. It must hold that $\partial r(x)/\partial w(x) < 0$ and $\partial w(x)/\partial \bar{n} > 0$ because workers are more productive when $\bar{n}$ increases. However, although the sign of this effect is expected to be negative (so reducing frictions will lead to lower rents), it is expected to be small in practice because intra-city wage variation in identical jobs tends to be small (*e.g.* due to competition and collective bargaining agreements). When we assume that the wages are identical within the city, the second term completely vanishes.[5]

The third term is the external effect, which reflects the value of frictions on nearby properties. Because density exhibits a positive effect on productivity, and therefore rents, weaker density frictions will imply a positive external effect on property values in business areas.[6]

From this informal discussion, we can make two empirical predictions. First, when intra-city variation in wages is small, the impact of density frictions on business rents is dependent on an internal effect and an external effect. Second, when agglomeration economies are important ($\partial \pi(x)/\partial z(x) > 0$), and when controlling for the internal effect, we can use exogenous variation in employment density to identify a causal effect of agglomeration economies on office rents.

2.2 Density frictions and agglomeration economies in London

Density frictions preventing changes to urban density can arise from; the durability of buildings (Wheaton 1982), transaction costs (Buitelaar 2004), strategic behaviour (Munch 1976), idiosyn-

[5] In the sensitivity analysis we will include local area and firm fixed effects, which should effectively control for wage differentials between firms: within a small area, the same firm is unlikely to offer higher wages for one location.

[6] In line with Turner et al. (2014), one may argue that there is also the effect of restricted supply due to density restrictions. In our setting, we cannot clearly measure the latter effect, because we compare price changes *within* a city. By contrast, Cheshire & Hilber (2008) explicitly focus on the supply effect by comparing prices *between* office markets in Great Britain.

cratic owner-value (Nedzell & Block 2007), and planning regulations (Ball 2011). Although in any given instance it may not be possible to disentangle the individual impacts of each potential source of density friction, in the case of London it is reasonably well-established that the principal density friction is planning regulations. London has one of the most extreme and long-standing regimes of building development control in the developed world, both in terms of the quantity of land made available for development and permissible building height (Cheshire & Hilber 2008, Hilber & Vermeulen 2016, Cheshire et al. 2018). Land supply for urban development has been tightly constrained in the UK since 1947, and the supply of each legal category of use is separately regulated. A maximum height restriction of 27 m was introduced in 1890, right at the time that steel building frame and passenger lift technology was allowing the construction of skyscrapers elsewhere in the world (Turvey 1998, Inwood 2005). Similar absolute height limits on new development continuously operated across London until the 1980s, at which point local authorities gradually removed them in favour of a more discretionary planning system. However this planning system is still lengthy, expensive, and uncertain (Ball 2011); particularly for tall building permissions (Kufner 2011, Cheshire & Dericks 2014).[7]

Moreover, almost half of Inner London and a third of Greater London remain off-limits to higher density development as a result of historic designations including; Conservation Areas; the Thames Policy Area; Protected long-distance views of St. Pauls Cathedral, the Monument, the Tower of London, 43 'strategic views' of other locations; a protected 'Green belt', and over 37,000 buildings and structures in Greater London which cannot be altered. Unsurprisingly, the upshot of these many decades of strict planning controls has been the preservation of urban densities in London more characteristic of the 19th rather than the 21st century.[8]

This extensive system of development control is consistently implicated as the principal reason for London registering the most expensive office rents in the world and more than twice as expensive as any other major European city (CBRE 2015, Cushman-Wakefield 2015). Consonant with this interpretation, research by Cheshire & Hilber (2008) show that the regulatory burden on office development in London was higher than for any major office location in Western Europe

[7] Research by Mayo & Sheppard (2001) show that both length of planning delay and the regulatory variance (riskiness) of the development decisions is important in reducing building supply, and therefore in creating density frictions.

[8] For instance the average building height in London's primary financial district, the City of London, is a mere 8-floors.

or the US, and provide direct evidence that the British planning system is indeed the cause.

Theoretically it is also reasonable to assume that planning regulation is the dominant density friction in London due to the fact that other possible frictions are likely to be self-limiting. Specifically, when the supply of developable land is constrained due to; redevelopment costs, transaction costs, strategic behaviour, or idiosyncratic owner-values; prices could eventually rise to a level where these barriers are overcome. By contrast, regulatory frictions may not respond to the price system or may even be strengthened as prices rise by special interest groups like land owners (Hilber & Robert-Nicoud 2013). It may not therefore be an exaggeration to claim that constraining planning regulations are a necessary condition for frictions to have an appreciable and long-lived influence on density. Moreover, the more pronounced the density frictions, the more likely it is that regulations are their cause. These assertions are lent empirical support by Hornbeck & Keniston (2017) who found that a large positive effect on land values which appeared as a result of the Great Boston Fire of 1872 (before development had been constrained by regulation) had entirely disappeared by 1894. But by contrast, in even-then tightly constrained San Francisco, the positive local density effects of the 1906 Earthquake and Fire have persisted to this day (Siodla 2015). Similarly, Akee (2009) recorded pronounced housing density and price differentials in adjacent but differently regulated Indian-trust and non-trust plots in Palm Springs, but once regulations were homogenized in the 1970s their densities and prices rapidly converged. If density frictions other than regulation are economically meaningful, such outcomes should not be observed.

Planning regulations in London may indeed be having a deleterious effect on density and by consequence agglomeration economies. London is a global financial center and personal relationships are a fundamental requirement for the establishment of trust, the production of knowledge, and the completion of complex transactions which require the input of many suppliers (Taylor et al. 2003). Thus proximity may be a source of competitive advantage. It is well-known that London has distinct office submarkets which cater to specific industries, for instance banking and finance in the City of London and private equity in the West End. However, even within these submarkets specific industry segments commonly co-locate. For instance, the eastern core of the City of London is the prime location for the major insurance houses, and in the West End the elite hedge funds cluster just east of Hyde Park. Furthermore, many of these clusters have been in existence for centuries and have only been displaced in exceptional circumstances.[9] The ubiquitous and sustained presence of such clusters suggests that agglomeration economies in London could strongly influence productivity, and by implication that density frictions there may have large economic effects.

2.3 The Blitz

Although London was attacked periodically throughout WWII, the civilian population was most intensively targeted during the period known as the Blitz, which lasted the 8.5 months between September 7$^{\text{th}}$ 1940 and June 6$^{\text{th}}$ 1941. Hitler's explicit goal in the Blitz was to 'erase' London, and it was intended that these attacks would finally break the resolve of the defending population, as the Luftwaffe had recently achieved at Guernica, Warsaw, and Rotterdam (Goss 2010). During the Blitz, the Luftwaffe dropped 18,291 tons of high explosives and countless incendiaries on London, destroying or damaging 576,947 homes: or 73% of the housing stock, and killing 19,622 of London's 4,013,400 residents (Ray 1996, p. 264, London Country Council 2005, p. 22).[10]

During the Blitz Luftwaffe bombers operated almost exclusively at night and at close to their maximum altitudes and speeds.[11] Even under pristine daytime conditions and in the absence of enemy action, when flying at high altitudes the Luftwaffe was only able to achieve a circular error probable between 260-380 m from their point of aim (Downes 2008, p. 286).[12] Therefore, even if German aircrews could successfully navigate to their target, the inherent inaccuracy of unguided gravity bombs released at altitude would necessarily lead to indiscriminate attacks. Manoeuvring to specific targets at night, in imperfect weather, under black-out conditions below, while lacking modern day navigation systems, and avoiding searchlights, flak batteries, and decoy 'starfish' targets, presented a significant challenge to WWII airmen. For instance, during

[9] Severe damage from the Blitz, for instance, is known to have caused the permanent relocation of some long-lived commercial clusters (Marriott 1989, p.69).

[10] The damaged homes figure consists of 'homes demolished or damaged beyond repair' plus 'homes damaged but repairable' as of June 12$^{\text{th}}$ 1941. Deaths attributed to the Blitz consist of those killed by air raids between September 1940 and May 1941 inclusive.

[11] When fully loaded German bombers could operate between 15,000-20,000 ft (4,600-6,100 m) at 200 mph (320 km/h). German bombers flew at these heights and speeds in order to evade searchlights, and the intercepting aircraft and targeted anti-aircraft fire that such discovery would bring.

[12] Circular error probable is a standard measure of a weapon system's accuracy, and refers to the average radius from the point of aim within which 50% of ordnance (bombs) can be expected to fall.

this period only one in five British air crews operating under similar night-time conditions flew to within 8 km of their intended German targets, and the 'best' British circular error probable averaged a paltry 4.8 km radius from point of aim (Hastings 2010).[13]

In anticipation of these difficulties, prior to the war the Germans had developed radio systems that could direct bombers in total darkness to within 1.6 km of their targets (Hyde et al. 1987*b*, p. 126). But by the time the Blitz had started, these navigational aids were being continuously jammed and falsified by the British leaving them of limited effectiveness (Price 2009). On clear moonlit nights however, German airmen would have been able to visually navigate to a degree via the land-water boundary of the River Thames and its distinctive contours (Ingersoll 1941). Nevertheless, both locating specific targets and then accurately striking them at night remained extremely problematic. For instance, in the first two months of bombing, Battersea Power Station – perhaps the largest single target in London, had only received one minor hit ('a nick'), no bridge over the River Thames had been struck, and the docks despite great damage were still functioning (Ingersoll 1941). Realising the futility of hitting specific targets, from the night of October 8$^{\text{th}}$-9$^{\text{th}}$ the German command switched from assigning bomber crews specific points of aim to targeting areas often comprised of several square miles, which they referred to as '*zielraum*' (Hyde et al. 1987*b*, p. 24). In addition, London, offering a larger target area, was deliberately attacked chiefly during moonless nights so that raids on smaller cities where greater accuracy was required could be conducted with the aid of moonlight (Hyde et al. 1987*b*, p. 42). Due to these factors, the Luftwaffe's night-time bombing at altitude during the London Blitz was by default a widespread 'area' phenomenon.

2.4 Blitz bomb strikes as a determinant of current density frictions

Although the Blitz ended more than 75 years ago, we argue that the density of Blitz bombings is a suitable proxy for local density frictions today because greater local bombing leads to; *(i)* more permissive local regulation, *(ii)* which promotes greater local redevelopment and leads to higher local densities that are then preserved by the planning system.

To demonstrate each of these assertions first note that culturally significant locations are less

[13] Low altitude attacks such as the famous Royal Air Force dam busting 'Operation Chastise', could however achieve impressive accuracy.

likely to survive in areas that have been heavily bombed, and therefore their surrounding areas are also less likely to later receive historic designations or be subject to heightened planning scrutiny. This relationship is clearly evident in Rotterdam where, four months prior to the London Blitz, its city center was devastated by the Luftwaffe while surrounding areas went largely unscathed.[14] Koster et al. (2012) observed that the boundaries of now conserved – and hence lower density areas – are sharply delineated by the extent of this bombing. Visual inspection of London also supports this view, with the heavily bombed eastern portion of the City of London and Docklands now featuring London's most permissive height restrictions. The second argument: that tighter regulations then deter local development and lowers density is supported by; Been et al. (2016) who found specifically that developers in New York shun preservation districts in favour of non-designated areas, and by many other studies of land use regulation generally (Glaeser & Gottlieb 2009, Jackson 2016, Levine 1999, Mayer & Somerville 2000).

Note that the causal chain argued above has demonstrably played out in London for destructive episodes other than the Blitz. The 1992 bombing of the 1903 Baltic Exchange building is now responsible for the erection of one of the tallest office buildings in London: Norman Foster's 'Gherkin'. At the time, the Baltic Exchange was an historically protected 'listed' building, which by law could not have been altered without special government permission. However, the irreparable damage caused by this attack led planners to approve the redevelopment of this 6-storey heirloom into a 40-floor icon. Although this case is exceptional, the Blitz bombings facilitated similar local regulatory relaxations across the entirety of Greater London. We provide more formal evidence for this contention in the next section.

3 Randomness of bombings and the relationship with frictions

3.1 Blitz bombings data

Our data on the location of bombs dropped on London during the Blitz comes from Bomb Sight. This data originates from the WWII London bomb census, and contains the geographic locations of all the high explosive bombs that fell in London from piloted night-time raids

[14] Unlike England, the Luftwaffe had air superiority over Holland and so could operate at low altitudes and therefore with ruinous accuracy.

between October 7th 1940 and June 6th 1941.[15] The locations where the much smaller and more numerous incendiaries fell were not recorded. One may argue that the bombs which fell in large water bodies or parks were less likely to have been reported, which implies measurement error. We address this issue in our research design.

For our purposes, to use information on the locations where bombs fell is preferable over the locations of actual Blitz damage because areas and buildings deemed 'significant' were heavily protected from incendiaries by dedicated fire crews who would have been able put out the majority of their fires before they could cause real damage. Moreover, low-quality buildings may have been less likely to survive the bombing and may not have been restored if damaged (see Hulten & Wykoff 1981). Hence, measures of actual damage could be correlated with the quality of local buildings at that time. Moreover, the Blitz bomb location data is available for Greater London, while the damage maps are only available for Inner London.

We also digitize maps of the target areas ('*zielraum*') used by German bomb crews during the Blitz. Their average size is 0.73km^2, which is consonant with the view that night-time bombings could not be very precise.

In Figure 1 we present a map of the bomb density for Greater London based on the exact locations bombs fell during the Blitz. It is immediately observed that bombings are concentrated in Inner London. In particular the City of London and the boroughs of Westminster and Southwark were the most heavily bombed. Bermondsey, a district of Southwark, has the highest bomb density. In Appendix A.1 we map bombs at a local level for the City of London and Docklands. The variation at this more local level (*e.g.* within a borough) appears to be as good as random, but we will carefully test this presumption in the next subsection. It is also observed that, although *zielraum* are everywhere in Greater London, there is a concentration of relatively small target areas in Inner London along the Thames, which was used for navigation. For the economic analysis we partition Greater London into small areas based on the distance to the nearest *zielraum* and borough and control for distance to the River Thames.

[15] Since the final major daylight raid of the Blitz took place on September 30th 1940 and minor daylight raids were abandoned altogether by early October, the bomb location data used in this paper exclusively comprises raids conducted under the less accurate night-time conditions.

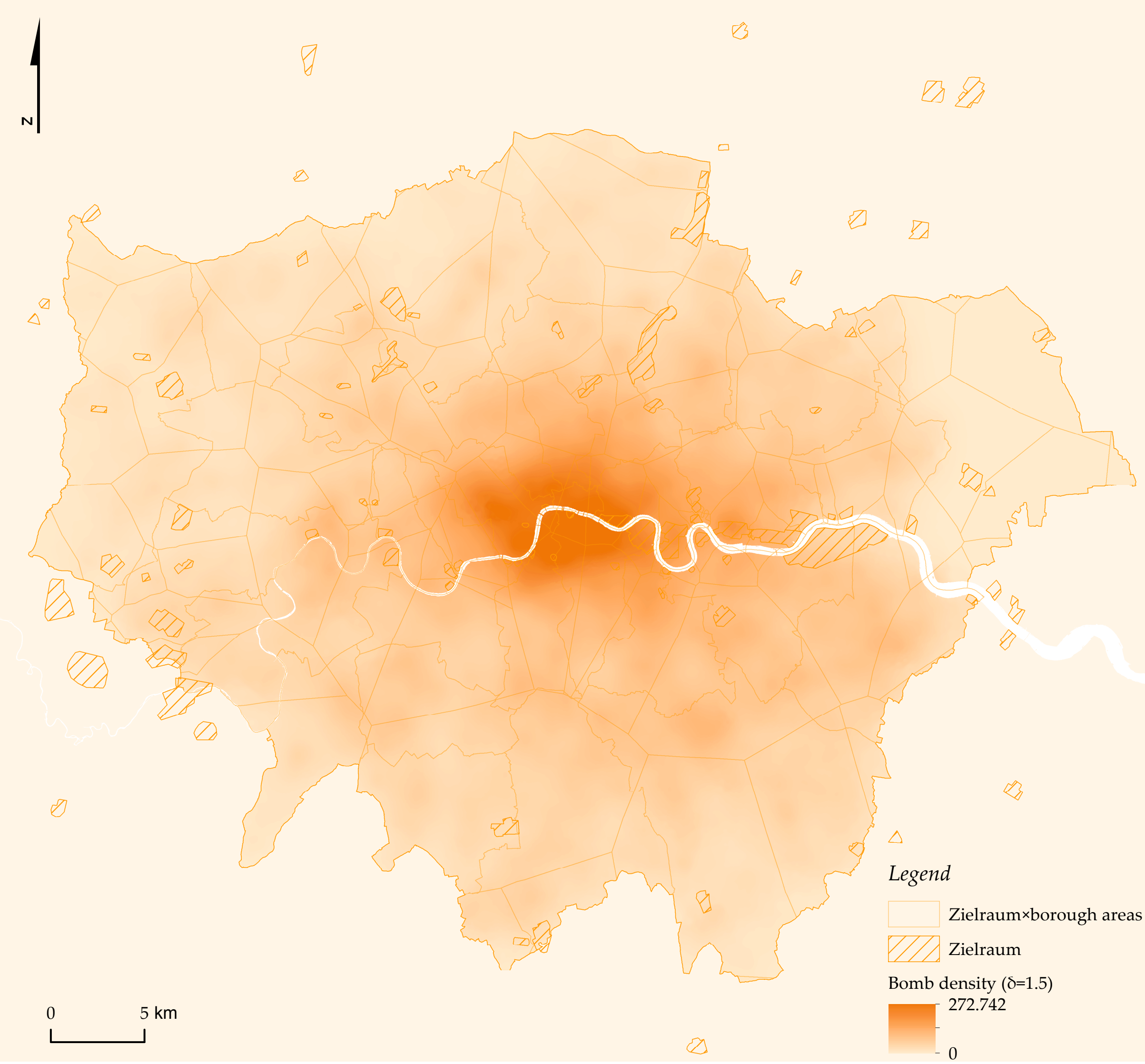

FIGURE 1 – BOMB DENSITY AND ZIELRAUMS

Notes: We calculate the bomb density as $B(x) = \delta \int_0^Z \mathrm{e}^{-\delta d(x,z)} b(z) \mathrm{d}z$, where $b(z)$ is an indicator that equals one when a location is hit by a bomb, $d(x, z)$ is the distance in km between x and z and δ is the decay parameter, which we set to 1.5. See the sensitivity analysis for more details regarding δ.

3.2 Are the bombings spatially random?

If bombings are randomly distributed over space, it is unlikely that there will be a correlation between unobservable locational endowments and bomb density. Hence, here we aim to show that bombings are not statistically significantly concentrated in space. One obvious approach to test this would be to gather data on the dependent variable of interest before WWII and regress that on bomb density (see Redding & Sturm 2016). However, unsurprisingly, locally granular pre-war data on office rents do not exist.

Hence, we employ a point-pattern methodology to test for the concentration of bombings that exploits that fact that our data is continuous over space.[16] More specifically, we employ the method proposed by Duranton & Overman (2005, 2008). This concentration index controls for overall agglomeration, is invariant to scale and aggregation and, importantly, provides an indication of statistical significance. Below, we briefly discuss the procedure. For more details, we refer to Duranton & Overman (2005, 2008).

Let $K(d)$ denote the estimated kernel density at a given distance d, d_{ik} denotes the distance between location i and k, where $i = 1, ..., n$. Then:

$$\hat{K}(d) = \frac{1}{n(n-1)h} \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \Omega\left(\frac{d - d_{ik}}{h}\right), \tag{3}$$

where n is the total number of bombs that fell, h is the bandwidth and:

$$\Omega(\cdot) = \frac{1}{\sqrt{2\pi}} \mathrm{e}^{-\frac{1}{2}\left(\frac{d-d_{ik}}{h}\right)^2}. \tag{4}$$

The above equation implies that we use a normal density function. Following Duranton & Overman (2005, 2008) and Klier & McMillen (2008), we use a bandwidth h equal to Silverman's plug-in bandwidth (see Silverman 1986). More specifically, $h = 1.06\sigma_{d_{ik}} n^{-1/5}$, where $\sigma_{d_{ik}}$ is the standard deviation of the estimated bilateral distances between bombs. Distances d cannot be negative, so we use the reflection method, proposed by Silverman (1986), to deal with this issue.

We aim to test whether the estimated concentration is statistically different from a random geographical pattern, so we have to define counterfactual location patterns. The most obvious way would be to assign bombs to random locations within Greater London. However, this approach would not take into account that bombings usually occur in sequence. On bombing runs, airplanes flew in formation at specific speeds, in a certain direction, and dropped multiple bombs in succession. Indeed, if we look more closely at the data, neighboring bomb locations often follow line patterns. Our counterfactual should therefore incorporate this feature; otherwise we might erroneously conclude that bomb sequences represent significant spatial concentration, when in fact the overall pattern of bomb sequences with respect to analysis areas are random.

[16] It has been argued that many measures of concentration use arbitrary spatial units (such as provinces, local authorities or postcodes), which may be problematic as they may lead to biases in the measure of concentration (Briant et al. 2010).

To construct the counterfactual, we use information on the technical characteristics of the Luftwaffe bombings. The principal bombers used by the Luftwaffe during the Blitz were the Junkers Ju 88, Heinkel He 111, and Dornier Do 17, but by end of 1940 the obsolete Do 17 had been largely phased out (Hyde et al. 1987*a*). Both the Ju88 and He 111 maximum bomb loads were about 2,000 kg in total, with the Ju 88 usually carrying between 2-14 individual bombs and the He 111 carrying 6-10 (Hyde et al. 1987*a*). The average cruising speed of the Ju 88 and He 111 when fully loaded with bombs was roughly 300kph. Since a greater number of bombs with lighter individual weights was the most common payload, we assume that on average 10 bombs were dropped within a time interval of five seconds, which implies that the bombs struck in a relatively straight line, each about 40 m from the last. For each bootstrap run we pick $n/10$ randomly drawn locations and generate 10 bombing locations along a line, based on a randomly drawn angle and the average cruising speed. This counterfactual is of course not perfect. It might be that the locations of bombings are spatially autocorrelated in different ways. For example, when airplanes observe fires caused by previous bombing runs, they may target these areas as well. Also, planes often flew in squadrons perhaps leading to certain patterns of concentration. In all these cases, we might be inclined to find spurious patterns of concentration, even if the overall pattern of these bombing clusters was random in practice.

A second feature that a valid counterfactual should incorporate is that the bombings may not be spatially random at the level of Greater London because the Luftwaffe may have used the River Thames to navigate. In addition, there may be geographical features, such as large parks or water bodies in which bomb strikes were not well recorded. Finally, as the goal of the bombings was to demoralize the population, it is logical to assume that particularly dense 'areas' were targeted. We therefore employ a weighted bootstrap method, in which weights are dependent on the conditional probability that a local area was bombed. We use a conditional logit model in which the probability to be bombed is given by:

$$\Pr[b(x)] = \frac{e^{\psi g(x) + \lambda(x)}}{\sum_{z=1}^{Z} e^{\psi g(z) + \lambda(z)}}, \tag{5}$$

where $z = 1, ..., Z$ are other locations, $g(x)$ are geographical features and $\lambda(x)$ are fixed effects. Location fixed effects should be small enough to effectively control for pre-war differences in population density, while not being so small as to absorb the effect of interest. We therefore choose to include either borough fixed effects or *zielraum*×borough fixed effects.[17] For the latter we calculate for each location x in a borough the distance to the nearest *zielraum* and add an identifier for the nearest *zielraum*.

We estimate ψ and $\lambda(x)$ to obtain $\hat{\Pr}(b(x))$. We also run specifications where we include additional location and neighbourhood attributes to determine $\hat{\Pr}(b(x))$.

To investigate whether there is statistically significant concentration of bombings we calculate the difference between $\hat{K}(d)$ and the upper confidence band of the randomly generated bomb patterns, denoted by $\overline{K}(d)$. Hence, we define an index of concentration $\mathcal{C}$:

$$\mathcal{C} = \int_0^{\bar{d}} \max \hat{K}(d) - \overline{K}(d)(d)d. \tag{6}$$

When $\hat{K}(d) > \bar{K}(d)$ for at least one $d \in [0, \bar{(}d)]$, we conclude that bombs are statistically significantly concentrated; *i.e.* when $\mathcal{C} = 0$, bombings are (conditionally) random. Because we are mainly interested in local effects, we restrict $\bar{d} = 5$. Furthermore, we define the 95% confidence interval so that $\underline{K}(d) = 0.025$ and $\overline{K}(d) = 0.975$ To define $\underline{K}(d)$ and $\overline{K}(d)$, we treat each of the estimated density functions for each simulation as a single observation. Following Duranton & Overman (2005), we choose identical local confidence levels in such a way that the global confidence level is 2.5%. Note that, because we have so many bombs, the confidence intervals are very tight and therefore the data is predisposed to find a statistically significant concentration of bombings.

We report the results when we estimate the local and global concentration indices as per (6) for Greater London in Table 1. We run 250 bootstrap simulations, but we have experimented with a higher number of replications, leading to very similar results. In column (1) we randomly assign bombs to locations, where we do not take into account that bombs were dropped in consecutive series. We find then that bombs are statistically significantly concentrated, as $\hat{\mathcal{C}} = 0.0379$. When we generate a counterfactual pattern only based on line patterns of bombings, we still find that

[17] The median area of the 33 boroughs in Greater London is 38.68 km^2. The median size of a *zielraum*×borough area is only 2.84 km^2

Table 1 – Concentration of bombings

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Concentration index, $\mathcal{C}$	0.0379	0.0323	0.0240	0.0034	0.0000	0.0000	0.0000
Average of $\hat{K}$	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163	0.0163
Average of $\underline{K}$	0.0085	0.0110	0.0112	0.0142	0.0142	0.0150	0.0149
Average of $\overline{K}$	0.0095	0.0158	0.0134	0.0164	0.0174	0.0169	0.0169
Probability weights dependent on:							
Geographical attributes (14)	No	No	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (49)	No	No	No	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	No	No	Yes	Yes	Yes
Location attributes (16)	No	No	No	No	No	Yes	Yes
Neighbourhood attributes (10)	No	No	No	No	No	No	Yes
Number of observations	28,324	28,324	28,324	28,324	28,324	28,324	28,324

Notes: For the construction of the counterfactual we assume that airplanes fly at 300 km/h and drop 10 bombs within 5 seconds. We furthermore use probability weights in the bootstrap procedure dependent on a conditional logit model. We refer to Appendix A.4 for results.

there is statistically significant concentration (column (2)). The concentration index is reduced to 0.0240 if we take into account that bombings may depend on distance to the River Thames and other geographical features that may imply that bombs have not been recorded (column (3)). The results of the conditional logit models that generate the probability weights are discussed and reported in Appendix A.4.

In column (4) we show results based on the inclusion of borough fixed effects. This is a strong predictor of the locations of bombs, as the concentration index is now reduced by another 90%. However, given that bombings are still not entirely random, we need more detailed fixed effects. When we include more detailed *zielraum*×borough fixed effects in column (5), we find that bombings are conditionally random as $\hat{\mathcal{C}} = 0$.[18] We illustrate this graphically in Figure A5 in Appendix A.4 where we display the 95% confidence intervals for the unconditional counterfactual and the conditional counterfactual. In the latter case, the estimated K-density falls entirely within the 95% confidence bands. The randomness of bombings is confirmed when we include additional location attributes (*e.g.* distance to a highway, whether a property is in a conservation area) and neighbourhood attributes (*e.g.* the average household size, the share of immigrants) in respectively columns (6) and (7) of Table 1. In the empirical analysis we therefore will control for *(i)* distance to the River Thames and other geographical features, and *(ii)* *zielraum*×borough fixed effects. The inclusion of the River Thames is natural due to the fact that it could have

[18] In the sensitivity analysis we make sure that the choice of fixed effects does not influence our results.

been used for navigation on certain nights and, ceteris paribus, it may have been easier for bomber crews to target areas of London closer to it.[19] Similarly, *zielraum*×borough fixed effects implicitly capture the extent to which the concentration of bombs was related to the presence of potential targets.

3.3 Are the bombings correlated to density frictions?

To further support the anecdotal evidence that bombings are correlated with density frictions presented in Section 2.4, it is desirable to more formally test this supposition. In Appendix A.2 we first show that a higher bomb density in local authorities is associated with a higher acceptance rate of commercial planning proposals, the latter being commonly used as a proxy for restrictiveness of land use policies (see e.g. Hilber & Vermeulen 2016).

To further investigate whether density frictions are important and have an impact on current building heights, we obtain the data from the Ordnance Survey on all buildings in Greater London and their corresponding building heights as of 2014. See for more information on the data Appendix A.3.[20] We make a distinction between the *internal* effect of bombings, which implies that bombed building sites are expected to host taller buildings. However, bombs may generate damage in larger areas than a single site, redevelopments are strongly spatially correlated, and density restrictions are often street or neighbourhood-specific. Hence, we expect that an *external* effect may also be important: a higher bomb density in the neighbourhood may lead to taller buildings throughout, *e.g.* because of fewer height restrictions related to pre-WWII buildings. We report results for office buildings in Table 2.

In column (1) we estimate a naive regression of the building height of offices on bomb density, a dummy indicating whether the building was bombed and building controls. The coefficient related to bomb density seems to suggest that an increase of one standard deviation in bomb density leads to an increase in height of 13%. The internal effect also seems important: buildings that have been hit by a bomb are $(e^{0.0488} - 1) = 5.0\%$ taller. The effects are very similar once

[19] The location of Barrage Balloons employed during the war could not have materially influenced our finding that Blitz bombings are conditionally random. The primary purpose of Barrage Balloons was to force bombers to higher altitudes so that their attacks would be less precise. While the maximum altitude of Barrage Balloons was only $1,524$ m, German bombers maintained altitudes three and four times this during the Blitz. Moreover, Barrage Balloons were often tethered near open spaces and gardens, for which we control in the empirical analysis.

[20] Unlike Siodla (2015) we do not have data on any intervening years and therefore cannot examine dynamic patterns in density changes which may have emerged in the interim.

Table 2 – Bombings and office building height

(Dependent variable: the log of office building height in m)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
Bomb density, $B(x)$, $\delta = 1.5$ *(std)*	0.1304***	0.1000***	0.0799***	0.0692***	0.0636***	0.0566***
	(0.0009)	(0.0014)	(0.0023)	(0.0032)	(0.0032)	(0.0032)
Building site hit by bomb, $b(x)$	0.0488***	0.0526***	0.0521***	0.0510***	0.0495***	0.0548***
	(0.0151)	(0.0148)	(0.0142)	(0.0136)	(0.0134)	(0.0133)
Building – footprint *(log)*	0.1170***	0.1179***	0.1126***	0.1148***	0.1153***	0.1113***
	(0.0015)	(0.0015)	(0.0014)	(0.0014)	(0.0014)	(0.0014)
Building – listed	0.1126***	0.1011***	0.0463***	0.0375***	0.0279***	0.0262***
	(0.0067)	(0.0067)	(0.0064)	(0.0064)	(0.0064)	(0.0065)
Geographical attributes (10)	No	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	No	No	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	No	Yes	Yes	Yes
Location attributes (10)	No	No	No	No	Yes	Yes
Demographic attributes (10)	No	No	No	No	No	Yes
Number of observations	65,125	65,125	65,125	65,125	65,125	65,125
R^2	0.4213	0.4389	0.5007	0.5200	0.5343	0.5508

Notes: Bomb density is standardised *(std)* to have mean zero and unit standard deviation. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

we; control for geographic variables in column (2), include borough fixed effects in column (3), and use *zielraum*×borough fixed effects in column (4). In column (5) we further control for a host of location attributes, and in column (6) we add demographic controls. The coefficient of bomb density in column (6), 2, implies that a standard deviation increase in bomb density leads to buildings that are 5.7% taller. Furthermore, building sites that have been directly hit by a bomb have buildings on them that are 5.5% taller. Hence, these results seem to provide strong evidence that density frictions are weaker in areas that have been bombed more heavily.[21] We report similar results for non-office buildings in Appendix A.3.

4 Data and econometric framework

4.1 Data and descriptives

Rental data on office transactions consists of 9,202 leases signed in Greater London between 1997 and 2011 and was compiled by Estates Gazette. This data contains information on rents,

[21]We further find that buildings with a larger footprint tend to be taller: 1% increase in the footprint is associated with a 0.11% increase in the building height. Somewhat surprisingly, one can see that listed buildings tend to be taller than other buildings, although the effect is small once we include *zielraum*×borough fixed effects and controls. There are two reasons for this. First, larger and taller buildings are more likely to become listed: famous landmarks are hardly ever small and low buildings. Furthermore, listed buildings often imply height constraints for nearby buildings (*e.g.* based on view corridors), so that listed buildings remain taller than surrounding buildings.

floor space rented, year built or latest refurbishment year, the floor levels leased, total floor space in the building, and total floors in the building. We also have information on the geographic location of the building leased at the address level. We take employment information from the 2011 Census, which is available at the Output Area level – the lowest geographical level at which census estimates are provided: the median size is only 0.0333 km^2.[22] To enrich the spatial content of the employment data even further, we only keep land that is occupied by buildings and then randomly distribute the number of jobs in each Output Area over all buildings in an Output Area. We gather data on an extensive number of location attribute controls, such as the distance to the nearest highway, tube station, railway station, open space, water, all based on open source GIS data. Information on historic amenities is obtained from the National Heritage List for England. Demographic characteristics are obtained from the 2001 census. Furthermore, we gather data on population per parish in 1931, so before World War II. The median size of a Parish is 5.55 km^2. To enrich the spatial content of the population data, we only keep land that is currently occupied by buildings and then randomly distribute the number of people in each Parish over all buildings currently in a Parish.

Key descriptive statistics for the rental dataset are reported in Table 3. The average yearly rent for office space is £385 per m^2, which confirms that London is one of the most expensive office locations in the world. The average property is about 850 m^2. About 7% of the observations are in building sites that were directly hit by a World War II bomb. The average distance to the River Thames of the leased buildings is only 1.3 km, which confirms that we mainly observe leases in Inner London. 86% of the observations are in a conservation area, suggesting that although many areas had been bombed severely, many historic amenities still survived.[23]

In Figure 2 we plot agglomeration over space and indicate the locations of rental transactions. It is shown that most of our rental transactions are concentrated in Inner London, most notably, in West End and the City of London. Employment is particularly concentrated in and near the City of London. Areas close to the Bank of England have the highest employment densities. Because

[22] Preferably, one would have year-specific information on employment. Annual postcode area level employment is in principle available from the Business Structure Database Secure Access. However, after having digitally mapped this data, there were clearly some serious errors. For this reason we have preferred the Census data. In the sensitivity analysis, we will also use building volume as an alternative proxy for agglomeration economies.

[23] For the descriptives of the complete set of variables included in the regressions we refer to Table A2 in Appendix A.1.

Table 3 – Key descriptive statistics

	(1) mean	(2) sd	(3) min	(4) max
Rent *(in £ per m^2)*	384.8	179.4	10.76	1,507
Bomb density, $B(x)$, $\delta = 1.5$	215.0	43.52	0.124	269.2
Building site hit by bomb, $b(x)$	0.0709	0.257	0	1
Agglomeration, $A(x)$, $\delta = 1.5$	130,400	47,559	695.9	198,939
Distance to river Thames *(in km)*	1.320	1.291	0.00497	17.42
In conservation area	0.676	0.468	0	1
Size of the property *(in m^2)*	847.7	2,445	17.19	65,032
Building size *(in m^2)*	6,256	11,813	40.41	112,305
Number of floors in building	7.970	5.155	1	52
Floor of property	3.352	2.768	0	50
Building – newly constructed	0.0898	0.286	0	1
Building – refurbished	0.0916	0.288	0	1
Building – second hand	0.824	0.381	0	1

Note: The number of observations is 9,202

there is such a strong employment concentration in London's most important submarket, we will make sure in the sensitivity analysis that our results are not primarily driven by the City of London. In Appendix A.1 we provide a map of London's population distribution before World War II.

Figure 3 shows the relationship between bomb density and agglomeration. There is a strong positive relationship between bombings and the log of agglomeration: that is, heavily bombed areas have higher employment densities today. One might argue that this result arises from the fact that historically denser areas were bombed more heavily. The dashed line therefore represents a regression where we flexibly control for the log population density in 1931. Here we still observe a strong positive relationship between log of agglomeration and bomb density.

4.2 Econometric framework

We aim to analyse the causal effects of *(i)* density frictions on office rent, and *(ii)* the effects of agglomeration economies on office rents, using exogenous variation in employment density. As argued in Section 3 and shown in Section 3.3 and Appendices A.2 and A.3, a good proxy for density frictions is the density of bombs which fell during the Blitz. Bomb density at location x is constructed using an exponential distance decay function:

$$B(x) = \delta \int_z \mathrm{e}^{-\delta d(x,z)} b(z) \mathrm{d}z, \tag{7}$$

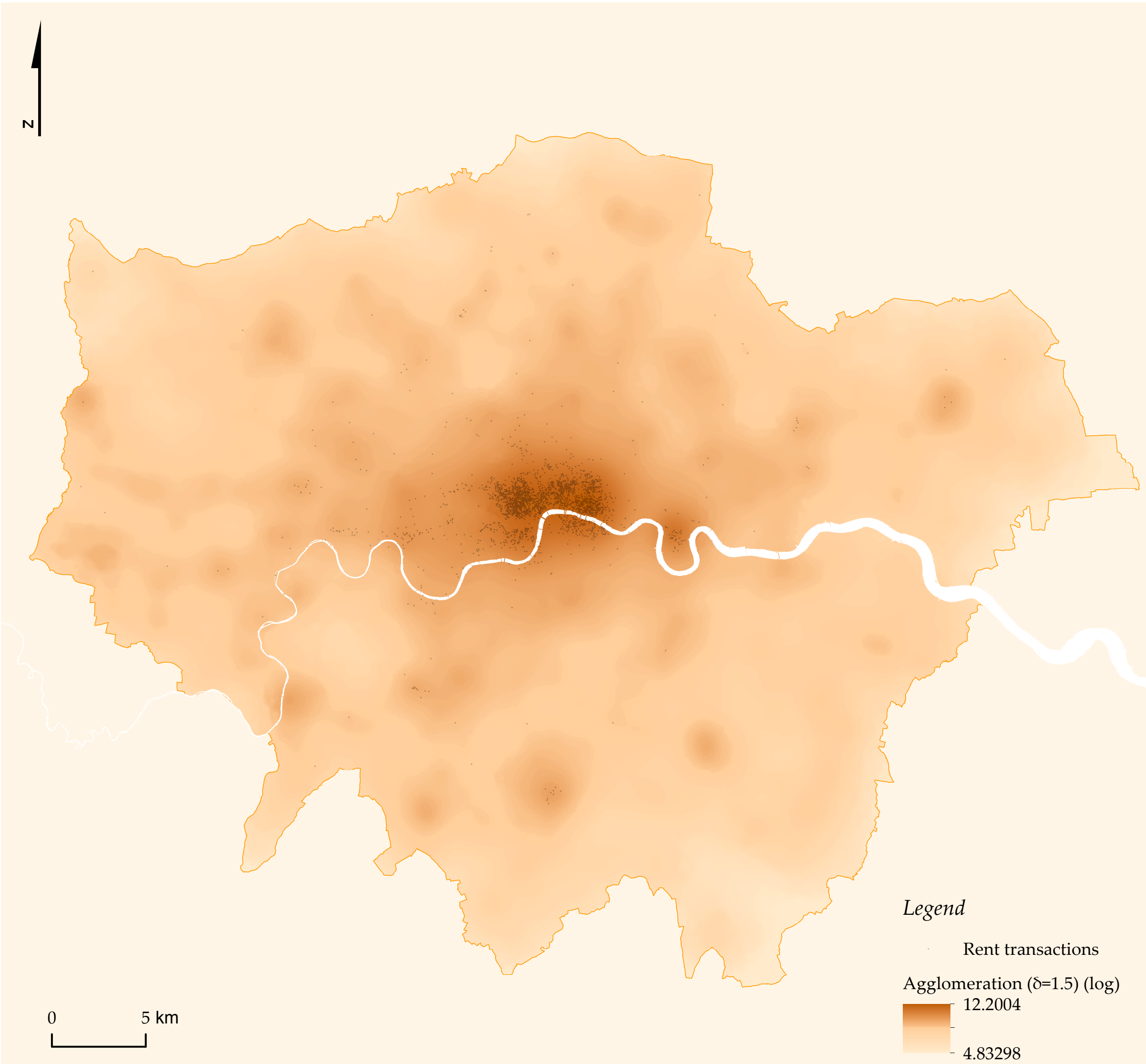

Figure 2 – Agglomeration and rental transactions

Notes: We calculate agglomeration as $A(x) = \delta \int_z \mathrm{e}^{-\delta d(x,z)} n(z)\mathrm{d}z$ where $n(z)$ is the number of jobs at location z, $d(x,z)$ is the distance in km between x and z and δ is the decay parameter, which we set to 1.5. See the sensitivity analysis for more details regarding δ.

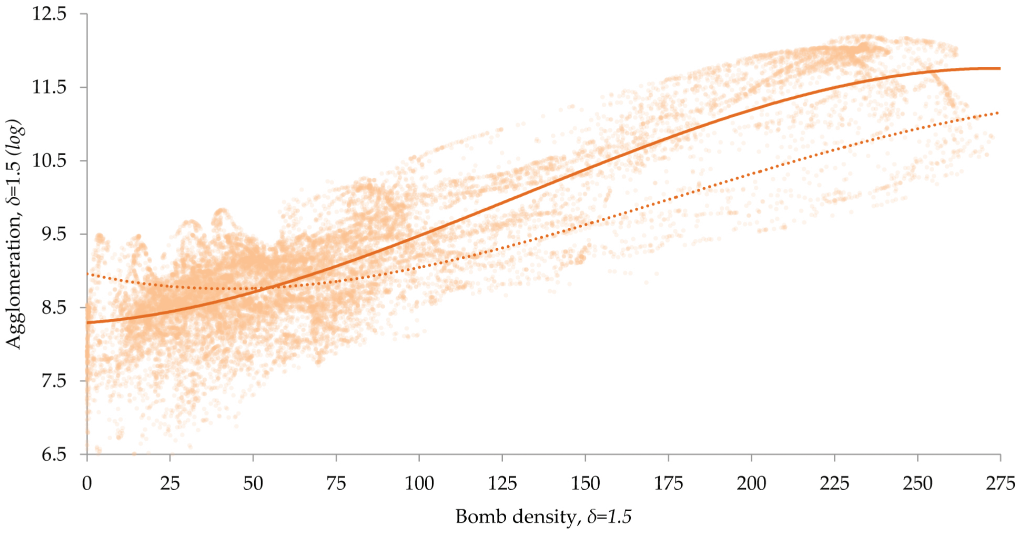

FIGURE 3 – BOMB DENSITY AND AGGLOMERATION

Notes: We calculate the bomb density as $B(x) = \delta \int_z e^{-\delta d(x,z)} b(z) dz$, where $b(z)$ is an indicator that equals one when a location is hit by a bomb, $d(x,z)$ is the distance in km between x and z and δ is the decay parameter, which we set to 1.5. Similarly, agglomeration is calculated as $A(x) = \delta \int_z e^{-\delta d(x,z)} n(z) dz$ where $n(z)$ is the number of jobs at location z, $d(x,z)$ is the distance in km between x and z and δ is the decay parameter. See the sensitivity analysis for more details regarding δ. The solid line represents a regression of log agglomeration on a third-order polynomial of bomb density, while the dotted line represents the same relationship, but controlling for a third-order polynomial of log population density in 1931.

where z is another location and $b(x)$ is an indicator that equals one when location z was hit by a bomb. The distance in km between x and z is $d(x,z)$,and δ is the decay parameter. In the econometric analysis, we set $\delta = 1.5$, which implies that most of the weight applies to bombs within 1 km of the firm location (see Figure A6 in Appendix A.5 for more details). We show robustness to this assumption in the sensitivity analysis.

Let $r(x,t)$ be the rent per m^2 of a property located at x in year t. A naive regression specification is given by:

$$\log r(x,t) = \alpha_0 B(x) + \alpha_1 b(x) + \eta(t) + \epsilon(x,t), \tag{8}$$

where α_0 should capture the external effect of density frictions and α_1 may capture the internal effect of bombings. Further, $\eta(t)$ are year fixed effects and $\epsilon(x,t)$ is an identically and independently distributed error term. It is unlikely that α_0 measures a causal effect of density frictions at this stage. The reason is that bombings are likely not random but based on both the population density before WWII commenced and the distance to the Thames. Further, because bomb strikes in water bodies and parks may not have been well recorded, we include geographic control variables $g(x)$, and *zielraum*×borough fixed effects $\eta(x)$.[24] Hence, in line

[24]We indicate the *zielraum*×borough areas in Figure 1.

with the findings in Section 3, we assume that bombings have been random, conditional on all differences between *zielraum*×borough areas and geographic differences. The quality of buildings may also not be randomly distributed over space (*e.g.* newer buildings in Inner London may have higher quality), we therefore also control for building attributes, denoted by $q(x)$. Note that it will be harder to interpret α_1 as the internal effect, because the building attributes may be a direct result of being hit by a bomb during the Blitz. It might be preferable to include (additional) location attributes $l(x)$, such as the distance to the nearest tube station, distance to open space, as well as demographic neighbourhood characteristics $c(x)$ to further control for locational characteristics that might be correlated with $B(x)$. We then estimate:

$$\log r(x,t) = \alpha_0 B(x) + \alpha_1 b(x) + \alpha_2 q(x) + \alpha_3 g(x) + \alpha_4 l(x) + \alpha_5 c(x) + \eta(t) + \eta(x) + \epsilon(x,t), \quad (9)$$

where α_2, α_3, α_4, α_5, and $\eta(x)$ are additional parameters to be estimated.

The second step in the empirical analysis is to measure the importance of agglomeration economies for office rents. The empirical literature cited in Section 1 provides evidence that agglomeration economies exist within cities and may decay within short distances, particularly for business services. Firms therefore cluster in dense central business districts and subcenters, and are likely willing to pay higher rents in these locations. For this interpretation to be valid there should be a positive correlation between employment density and office rents. We thus proxy for agglomeration economies by calculating weighted employment counts at each location:

$$A(x) = \delta \int_z \mathrm{e}^{-\delta d(x,z)} n(z) \mathrm{d}z, \quad (10)$$

where $n(z)$ is the number of jobs at z. Agglomeration economies are likely endogenous and may be correlated to unobserved locational endowments. However, given that bombings are (conditionally) random, we can use $B(x)$ as an instrument for agglomeration economies.[25] Hence,

[25] However, one could argue that density frictions could also impact property values directly via increased costs for developers so that the instrument is invalid. Because we focus on the local effects of frictions and the *rental property market*, we do not consider this as a major problem here. More specifically, consider the case that a tenant faces two identical buildings: one in an otherwise identical but more stringent area with higher costs for developers and another in an area with fewer restrictions. In a reasonably competitive market, developers cannot pass the costs of restrictions on to the tenant, because the tenant would always choose the building in the less restrictive area because it is cheaper. In particular, when we include detailed fixed effects, it seems very unlikely that our estimates capture a supply effect (Turner et al. 2014).

in line with (9), the first stage is given by:

$$\log A(x) = \gamma_0 B(x) + \gamma_1 b(x) + \gamma_2 q(x) + \gamma_3 g(x) + \gamma_4 l(x) + \gamma_5 c(x) + \kappa(t) + \kappa(x) + \epsilon(x,t), \quad (11)$$

where γ_0, γ_1, γ_2, γ_3, γ_4, γ_5, $\kappa(t)$ and $\kappa(x)$ are parameters to be estimated. Note that $\kappa(t)$ and $\kappa(x)$ refer to year and *zielraum*×borough fixed effects, respectively. The second stage is given by:

$$\log r(x,t) = \beta_0 \log \hat{A}(x) + \beta_1 b(x) + \beta_2 q(x) + \beta_3 g(x) + \beta_4 l(x) + \beta_5 c(x) + \mu(t) + \mu(x) + \epsilon(x,t), \quad (12)$$

where $\log \hat{A}(x)$ is the fitted value obtained in (12) and β_0, β_1, β_2, β_3, β_4, β_5, $\mu(t)$ and $\mu(x)$ are parameters to be estimated. $\mu(t)$ and $\mu(x)$ are again year and location fixed effects.

5 Results

5.1 Results for density frictions

The first set of regressions will focus on the 'reduced-form' effects of density frictions on rents, where we make a distinction between the hypothesized internal and external effect. Then, we will show that agglomeration economies are likely the reason why an external effect of density frictions exists. Table 4 reports the baseline results, where we regress office rents on bomb density and a dummy indicating whether a building site was hit a by a bomb. We cluster standard errors at the building level, because location attributes are available at the building level.[26] To facilitate interpretation we standardize bomb density so that it has mean zero and unit standard deviation.

Column (1) is a parsimonious specification of office rents on bomb density, year fixed effects, and building attributes. The coefficient suggests that when the density of bombs increases by one standard deviation, rents increase by 10.6%. It is shown that, conditional on control variables, properties that are on sites that were bombed are $\mathrm{e}^{-0.0690} - 1 = 6.7\%$ cheaper. When we would exclude building attributes, this effect is statistically insignificant and close to zero. Hence, for

[26] One may be worried that the standard errors are clustered at the wrong level. In Table A6 in Appendix A.6 we show that when we cluster at different spatial levels, such as output areas, wards or constituencies, the standard errors are slightly higher. On the other hand, the results remain statistically significant at the 1% level in all specifications.

Table 4 – Reduced form results: density frictions and rents

(Dependent variable: the log of rent per m^2)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
Bomb density, $B(x)$, $\delta = 1.5$ *(std)*	0.1055***	0.0987***	0.1326***	0.1341***	0.0963***	0.0835***
	(0.0078)	(0.0097)	(0.0148)	(0.0180)	(0.0179)	(0.0171)
Building site hit by bomb, $b(x)$	-0.0690*	-0.0539*	-0.0562**	-0.0464*	-0.0453*	-0.0369
	(0.0392)	(0.0297)	(0.0269)	(0.0246)	(0.0239)	(0.0227)
Size of the property *(log)*	0.0322***	0.0422***	0.0488***	0.0503***	0.0515***	0.0522***
	(0.0096)	(0.0086)	(0.0066)	(0.0064)	(0.0062)	(0.0061)
Floor of property	0.0184***	0.0167***	0.0148***	0.0152***	0.0160***	0.0155***
	(0.0024)	(0.0022)	(0.0019)	(0.0019)	(0.0018)	(0.0018)
Building size *(log)*	0.0105	0.0114	0.0230***	0.0256***	0.0328***	0.0309***
	(0.0129)	(0.0105)	(0.0076)	(0.0072)	(0.0070)	(0.0068)
Number of floors in building	0.0042*	0.0055**	0.0049**	0.0047*	0.0053**	0.0055***
	(0.0022)	(0.0023)	(0.0025)	(0.0025)	(0.0022)	(0.0020)
Building – newly constructed	0.2707***	0.2769***	0.2716***	0.2613***	0.2580***	0.2552***
	(0.0270)	(0.0242)	(0.0202)	(0.0202)	(0.0197)	(0.0192)
Building – refurbished	0.1371***	0.1316***	0.1233***	0.1284***	0.1285***	0.1306***
	(0.0232)	(0.0205)	(0.0168)	(0.0165)	(0.0163)	(0.0159)
Listed building	0.0879***	0.0720***	0.0040	0.0058	0.0003	-0.0019
	(0.0250)	(0.0243)	(0.0221)	(0.0213)	(0.0192)	(0.0184)
Latest refurbishment dummies (7)	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	No	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	No	No	Yes	Yes	Yes	Yes
Zielraum$\times$borough fixed effects (232)	No	No	No	Yes	Yes	Yes
Location attributes (13)	No	No	No	No	Yes	Yes
Demographic attributes (10)	No	No	No	No	No	Yes
Number of observations	9,202	9,202	9,202	9,202	9,202	9,202
R^2	0.2644	0.3958	0.5502	0.5742	0.5878	0.5966

Notes: Bomb density is standardised *(std)* to have mean zero and unit standard deviation. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

office tenants we cannot conclude that the internal effect is important, i.e. that buildings can be more efficiently used if newer.[27]

Building quality has a statistically significant positive impact on rents. Properties that are on higher floors are also more expensive; 1.8% per floor, which is in line with Liu et al. (2016). Not surprisingly, new and recently refurbished buildings are much more expensive than second-hand buildings (respectively 31.1 and 14.7%).

In Section 3 we showed that the bombings are not spatially random when geographic variables are omitted, such as distance to the Thames and whether a location is near a park or water body. Inclusion of such variables in column (2) does not change the results considerably: a standard deviation increase in bomb density implies a rent increase of 9.9%. In column (3) we add borough fixed effects, leading to a somewhat higher coefficient.

However, when including borough effects in Section 3 we still found weak evidence that bombings may be spatially concentrated. We therefore include more detailed *zielraum*×borough fixed effects in column (4). This should control for most of the differences in pre-war population density that may have influenced bomb density. The rents in more heavily bombed areas are still higher: a standard deviation increase in bomb density increases rents by 13.4%, which is essentially the same as in the previous specification.

When we control for a host of location attributes in column (5), the effect related to bomb density is somewhat lower. It should be noted that historic amenities seem to be important: properties either in or close to conservation areas are at least 25% more expensive.[28] In the final column (6), we include 10 additional demographic attributes. Although there is sometimes a statistically significant association between rents and demographics, the effect of bomb density remains essentially unaffected.

[27]Note however that buildings on bombed sites are taller (see Section 3.3), so for landowners bombed sites can be used more efficiently because buildings there are allowed to be taller.

[28]The coefficients of the control variables are available upon request. We find that office locations close to highways (within 125 m) are less expensive (about 6%), possibly due to noise and air pollution. Somewhat surprisingly, this also holds for locations near railway stations. Apparently, the benefits of having increased accessibility are not offset by the negative effects of being located close to transport nodes. We also find that residential properties within 250 m of a tube station are less expensive (about 4-10%), and those within 500 m tend to be more expensive which broadly confirms the results of that commuters want to be close to train stations but not too close (Bowes & Ihlanfeldt 2001, Gibbons & Machin 2005)

All specifications suggest a meaningful positive effect of bomb density on office rents, which implies that density frictions have a negative effect on office rents. Since density frictions in London seem to primarily arise from regulation, these results imply that the economic costs of development restrictions in the office market are high, and this is likely because agglomeration economies are important. Office rents may then be lower in areas bombed less heavily due to lower present-day employment densities. Whether this is a valid interpretation will be investigated in the next subsection.

5.2 Results for agglomeration economies

We have shown that bomb density *(i)* is random conditional on *zielraum*×borough fixed effects and geographical attributes. We also showed that *(ii)* higher bomb density is associated with higher office rents. We suspect that the main explanation for the latter relationship is the presence of agglomeration economies. In other words, density frictions lead to lower densities, thereby reducing agglomeration economies, leading to lower productivity and rents. This implies that there should be a positive relationship between employment density and office rents.

We start by reporting OLS results in Panel A, Table 5. Column (1) suggests that doubling employment density leads to an increase in rents of $(\ln 2 - \ln 1) \times 0.2058 = 14.26\%$. One may argue, however, that employment density is correlated to unobserved features of a location. We therefore control for geographic features in column (2) and include borough fixed effects and *zielraum*×borough fixed fixed effects in columns (3) and (4) respectively, leading to similar results. When we add a host of locational attributes, such as distance to highways, tube stations, and proximity to historic amenities, and control for 10 additional demographic variables in columns (5) and (6), respectively, the effect of agglomeration becomes somewhat stronger. In this full specification the results suggest that doubling agglomeration leads to a rent increase of about 25%. Hence, employment density seems to be a key determinant of office rents.

One may still suspect that employment density is endogenous, as otherwise more attractive locations are expected to attract more firms. This would imply that estimates of agglomeration economies are overstated. We therefore need to instrument for employment density. Blitz bombings are a suitable instrument for agglomeration since at local levels they are random,

Table 5 – Results: agglomeration economies and rents

(Dependent variable: the log of rent per m^2)

Panel A: Ordinary least squares	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
Agglomeration, $A(x)$, $\delta = 1.5$, *(log)*	0.2058***	0.2391***	0.2736***	0.3729***	0.3519***	0.3178***
	(0.0116)	(0.0150)	(0.0200)	(0.0280)	(0.0299)	(0.0306)
Building site hit by bomb, $b(x)$	-0.0553	-0.0515*	-0.0466*	-0.0442*	-0.0444*	-0.0378*
	(0.0400)	(0.0299)	(0.0268)	(0.0237)	(0.0232)	(0.0225)
Building attributes (15)	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	No	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	No	No	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	No	Yes	Yes	Yes
Location attributes (13)	No	No	No	No	Yes	Yes
Demographic attributes (10)	No	No	No	No	No	Yes
Number of observations	9,202	9,202	9,199	9,186	9,186	9,186
R^2	0.2906	0.4309	0.5622	0.5920	0.5998	0.6053

Panel B: Two-stage least squares	(1) 2SLS	(2) 2SLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS
Agglomeration, $A(x)$, $\delta = 1.5$, *(log)*	**0.1920*****	**0.1852*****	**0.3296*****	**0.3577*****	**0.3108*****	**0.2873*****
	(**0.0133**)	(**0.0169**)	(**0.0350**)	(**0.0467**)	(**0.0556**)	(**0.0579**)
Building site hit by bomb, $b(x)$	-0.0548	-0.0489	-0.0459*	-0.0439*	-0.0438*	-0.0372*
	(0.0399)	(0.0299)	(0.0269)	(0.0237)	(0.0233)	(0.0225)
Building attributes (14)	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	No	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	No	No	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	No	Yes	Yes	Yes
Location attributes (13)	No	No	No	No	Yes	Yes
Demographic attributes (10)	No	No	No	No	No	Yes
Number of observations	9,202	9,202	9,202	9,202	9,202	9,202
Kleibergen-Paap F-statistic	3,279	2,594	526.7	424.7	257.4	241.8

Notes: **Bold** indicates instrumented. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

but are associated with higher employment densities. In addition, conditional on the dummy variable indicating whether a site has been bombed, we strongly suspect that agglomeration economies are essentially the only possible explanation for the positive effect observed of Blitz bomb density on contemporary rents, and therefore that bombings do not have a direct effect on rents other than via higher densities. Panel B in Table 5 reports the results for the IV estimates where we instrument agglomeration with bomb density.

We first make sure that the instrument is strong (the Kleibergen-Paap F-statistic is above 200 in all specifications) and has the expected positive effect. In Table A7 in Appendix A.7 we report first-stage estimates. The elasticities of agglomeration with respect to bombing is about 0.55 and reduces to about 0.30 when adding controls and fixed effects.

In column (1) in Panel B of Table 5 we show that the elasticity of agglomeration is very similar to the corresponding specification in Panel A. This also holds if we include geographic control variables, borough fixed effects, and *zielraum*×borough fixed effects in respectively columns (2), (3) and (4). For example, the elasticity in column (4) in Panel B, Table 5, implies that if we doubled agglomeration, rents would increase by 25%, which is virtually identical to the corresponding OLS-specification. In line with previous results, the coefficient becomes slightly lower if we include a set of location attributes and neighbourhood controls in column (6). Here doubling agglomeration economies implies that rents would increase by 19.9%.

The elasticity of agglomeration with respect to productivity is typically between 0.02 and 0.075 (see Melo et al. 2009), but our results seem to point towards elasticities of 5 to 10 times larger. There may be several reasons for this. First, in contrast to previous studies we focus on the effects of employment density on rents, rather than wages. Because wages are often subject to collective bargaining agreements and significant competition, this will limit the possibility of agglomeration economies to be capitalized in wages, particularly within cities. We will investigate in Section 6 further whether wage differences matter in explaining the rent effect.

Second, London is a premier global financial center. We may therefore expect that agglomeration economies are more important and pronounced for the office sector here, where exchange in knowledge is of key importance. Hence, we might expect that localized density is much more important in London than in the medium-sized regional cities which typically dominate the samples of most other studies. Indeed, in a study of US commercial rents, Drennan & Kelly (2011) find that the effect of agglomeration more than doubles when they restrict their sample to submarkets within the largest urban cores. Furthermore, by focusing on offices, our sample primarily consists of industries that are likely to benefit substantially from locating in dense areas, while studies that focus on *e.g.* manufacturing are likely to find (much) lower effects.

Third, because firms on average spend less on real estate than on labour, the effects of agglomeration on total factor productivity on wages may be smaller. For example, for simplicity let us assume that firms' production technology is described by a constant returns to scale Cobb-Douglas utility function, firms spend about 25% of their budget on real estate, and that all agglomeration economies are capitalized in rents rather than wages. Given the estimate in column (6), Panel B in Table 5, the agglomeration elasticity with respect to total factor productivity would then be $0.25 \times 0.2873 = 0.072$, which is in the range provided by the literature.

5.3 Counterfactual analysis

Given our estimates of agglomeration economies we can approximate how the London office market would be affected today if the Blitz had not occurred, and therefore if density frictions had not been eased due to the relaxation of regulations that the Blitz provided. However, a common objection to this exercise would be that bombings reduced the cost of redevelopment in some places relative to others, so provided an incentive to redevelop in those places at the expense of others. This would imply that one could not infer aggregate gains, because at least part of what we measure is displacement. While this criticism usually is valid, London is a special case where rents are already many multiples above marginal construction costs across the entire city (Cheshire & Hilber 2008, Dericks 2013). Consequently for developers, a slight reduction in construction costs due to partial demolition caused by Blitz bombings is a detail. For London, planning permission is the relevant constraint and is not affected by displacement.

Nevertheless, we still have to make (strong) simplifying assumptions to be able to calculate aggregate agglomeration gains. First, we assume fully elastic demand, so that rents will not be directly affected by a change in the supply of offices. Second, we abstract from the inclusion of construction costs and do not take into account that it may become somehwat more expensive to construct taller buildings in denser areas. Hence, while these estimates illustrate the importance of density frictions they should be interpreted with caution.

We obtain additional data from the Department for Communities and Local Government, which has calculated the total available office space as well as the rateable value per m^2 across each of the 33 boroughs in Greater London. The rateable value is the appraisal-based yearly rent the property could have been let for on the open market on a particular date and is used for tax purposes. We make sure that in Inner London (where most of our data is from), the average rateable value is indeed close to the average rents in our dataset. Let B_S be the bomb density in counterfactual scenario S. Using data on the building type from the Points-of-Interest data, we determine whether each building in London is an office building. We then calculate the percentage change in agglomeration for each office building as $\mathrm{e}^{(\hat{\gamma}_0(B_S-B(x)))-1}$, where γ_0 is the estimated first-stage coefficient of the regression of agglomeration on bomb density (obtained from column (6), Table A7 in Appendix A.7). The total yearly monetary loss in agglomeration economies is then given by:

$$\begin{aligned}
&\int_x (\mathrm{e}^{\hat{\alpha}_0(B_S-B(x))}\mathrm{e}^{\hat{\gamma}_0(B_S-B(x))})r(x)T(x) - r(x)T(x)\mathrm{d}x, \\
&= \int_x (\mathrm{e}^{(\hat{\alpha}_0+\hat{\gamma}_0)(B_S-B(x))} - 1)r(x)T(x)\mathrm{d}x, \\
&= \int_x (\mathrm{e}^{((1+\hat{\beta})\hat{\gamma}_0)(B_S-B(x))} - 1)r(x)T(x)\mathrm{d}x,
\end{aligned} \tag{13}$$

where $r(x)$ is the rent and $T(x)$ the average office space per building at location x and $\hat{\alpha}$ is the estimated reduced-form effect of bomb density on rents (obtained from column (6), Table 4). Note that the first term $(\mathrm{e}^{\hat{\alpha}_0(B_S-B(x))})$ is the percent external effect of density frictions, while the second term $(\mathrm{e}^{\hat{\gamma}_0(B_S-B(x))})$ captures the percent effect due to a reduction in agglomeration. When for example the total m^2 of office space is reduced due to the presence of density frictions, the total revenues from office space will also markedly decrease, even if there were no external effects of density frictions ($\hat{\alpha}_0 \to 0$).

We consider two scenarios. In the first we assume that the Blitz did not happen, so that $B_1 = 0$ for all locations in London. In the second, we consider the situation where London had been

Table 6 – Counterfactual analysis

	Total m^2 of office	Average rent per m^2	*Case 1: No bombings* % Change in agglomeration	*Case 1: No bombings* Total change in rents (×million £)	*Case 2: Complete bombings* % Change in agglomeration	*Case 2: Complete bombings* Total change in rents (×million £)
Inner London Boroughs						
City of London	4,913,000	300	-65%	-1,088.95	15%	290.11
Camden	2,073,000	347	-50%	-417.14	64%	665.47
Hackney	530,000	189	-46%	-54.54	76%	108.93
Hammersmith and Fulham	755,000	237	-30%	-65.58	129%	340.53
Islington	1,389,000	228	-51%	-187.92	61%	273.42
Kensington and Chelsea	482,000	370	-42%	-90.09	88%	226.05
Lambeth	637,000	197	-45%	-66.73	79%	143.77
Lewisham	150,000	77	-36%	-5.06	108%	18.19
Southwark	1,241,000	240	-60%	-204.72	31%	128.88
Tower Hamlets	2,422,000	228	-54%	-348	50%	383.61
Wandsworth	319,000	154	-29%	-17.18	133%	97.24
Westminster	5,311,000	493	-58%	-1,762.60	36%	1,303.02
Inner London	20,222,000	327	-55%	-4,308.51	46%	3,979.22
Greater London	26,330,000	280	-46%	-4,457.72	76%	6,017.45

completely bombed-out, by imputing the bomb density achieved in Bermondsey – the most heavily bombed location in London – to all locations, so that areas were on average more than 200% more bombed than they had been. We refer to this scenario as 'complete bombings'. Note that the latter scenario is still an underestimate of the case of no density frictions, as planning restrictions are still in place in London's most heavily bombed areas. We aggregate the effects up to the Inner London Boroughs, Inner London, and Greater London. The results are reported in Table 6.

In line with Figure 2, we first observe that most of the office space is concentrated in Inner London, and in particular in the City of London, Westminster and the Docklands (Tower Hamlets). The rent differences can be stark: in Lewisham, the rent is only about 15% of the rent in Westminster. However, there are hardly any offices located there.

In the first scenario we consider what would be the change in agglomeration and the total rent revenue if the Blitz bombings had not taken place. It can be seen that the employment density would be much lower. In particular in heavily bombed boroughs like the City of London, Westminster and Southwark, agglomeration would be about 65% lower, and agglomeration in Greater London would on average fall about 50%. Not surprisingly, the implied losses in agglomeration economies would be substantial. For example, for Westminster this amounts to more than £1.7 billion per year. The total yearly loss in office rent revenues for Greater London would be almost £4.5 billion, which equates to about 1.2% of Greater London's annual GDP or 39% of its annual average growth rate.[29] Because most offices are located in Inner London and because Inner London was much more heavily bombed, the losses to the rest of Greater London in this scenario are rather small.

In the second scenario we consider the case where the whole of London had been as heavily bombed as the most heavily bombed district (Bermondsey). For the City of London, the level of agglomeration would be more than twice as high. However, in some areas like Hammersmith and Wandsworth, the differences would be even larger (up to 133%). However, because relatively few offices are located there, those areas contribute little to the total gain in revenues from reduced density frictions. In this scenario, the total yearly gain in rents due to increased agglomeration economies across Greater London would be substantial (about £6 billion). For Inner London, this effect is almost £4 billion. Hence, it seems that substantial gains could be achieved if density frictions were reduced. However, we do not take into account that with a greater supply of office buildings the rents would probably be lower, so this estimate is in fact an upper bound on the total rent revenues gained in this scenario.

6 Sensitivity analysis

In this subsection we investigate the robustness of our results. We examine robustness with respect to density frictions in Appendix A.8 and with respect to agglomeration economies in Appendix A.9. For density frictions we ensure that there is no internal effect on rents, *i.e.* that buildings are not more or less attractive or efficient once their site has been bombed. We further control for firm sorting by including firm fixed effects, and control (more) flexibly for the population density in 1931 and the distance to the Thames. We also exclude the City of London and estimate regressions where we only include Inner London. We additionally make sure that the results are robust to different definitions of fixed effects (*e.g.* constituencies and 1931 parishes). Finally, we show that the specific choice of our decay parameter δ is suitable. For the agglomeration sensitivity analysis we employ an alternative proxy for agglomeration – office building volume in the vicinity – leading to nearly identical results. Taken together these

[29] We obtain the estimate of London's GDP from the Office for National Statistics, which was estimated to be £364 billion in 2014.

various sensitivity checks support our chosen methodologies and the robustness of our results.

Previous research on agglomeration economies has frequently used housing prices as a proxy for commercial rents, because the latter are often more difficult to acquire. If land uses in a city are mixed, the rents of firms and households should be positively correlated.[30] This section investigates the extent to which the substitution of commercial rents for house prices is empirically valid. As most of London has mixed land use, we might expect results using house prices to be similar to those using office rents.[31]

For this analysis, we use data on house prices obtained from the Nationwide Building Society. The data provides information on 128,931 housing transactions, so the housing sample is substantially larger than the data on office rents and covers a much wider area of Greater London. In a recent working paper, Redding & Sturm (2016) provide preliminary evidence that house prices within 200 m of areas heavily damaged (and therefore bombed) by the Blitz may be lower, due to negative social interactions (*e.g.* in heavily damaged areas more public council housing may have been constructed after the war). We therefore include a control variable measuring the number of bombs within 200 m of the postcode, which should have a negative effect on house prices.

The results in Appendix A.10 show that the effects on house prices are lower in magnitude than the office market. However, the effects are most similar in areas of mixed land use (*i.e.* in which the ratio of employment to households is larger than one). In mixed areas, a standard deviation increase in bomb density raises house prices by 6.2%, which is not statistically significantly different from the baseline effect (the estimated effect in the office market is 8.5%) (see column (7), Table A11). When we test for the impact of agglomeration economies on house prices in mixed areas, we find that doubling agglomeration leads to a house price increase of 12.3%, which is less than half the estimated elasticity for the office market (see column (7), Table A12). This implies that using house prices to measure agglomeration economies may lead to an underestimate.

In line with Redding & Sturm (2016), we also find negative house price effects on the number of

[30] Lucas & Rossi-Hansberg (2002) show that in a mixed area, households' bid rents should be identical to bid rents for firms and independent of commuting costs.

[31] As an illustration, in about 50% of the output areas, the ratio of jobs to households is larger than 0.25 and smaller than 2.5.

bombs within 200m. Per bomb, this price decrease is 0.3%. In heavily bombed areas this implies a strong price effect of up to 15%. Note that we use data on bomb strikes, whereas Redding & Sturm (2016) use actual bomb damage data. Hence, given that we are able to replicate their result, this supports the validity of using bomb strikes in our estimations.

7 Conclusions

This paper exploits locally exogenous variation in the location of bombs dropped during the London Blitz to investigate how density frictions affect urban spatial structure, the functioning of property markets, and agglomeration economies. Our results indicate that the Blitz bombings have lowered local regulatory density frictions, thereby increasing local density, and that such locations now command significantly higher office rents. More precisely, we found that a standard deviation decrease in density frictions increases office rents by 8.5%, and that doubling employment density increases office rents by about 25%. These results are several multiples larger than those produced in previous research, but we argue this finding is consistent with the higher agglomeration economies thought to exist in elite global centers such as London, and is moreover robust to a wide range of sensitivity checks. Within London these effects also seem to extend further than those seen in other cities: to at least 1 km. Finally, we show that the use of house prices as a proxy for commercial rents in the agglomeration literature may in fact underestimate these effects.

We provide evidence that most of the density frictions observed in London are caused by regulation. This finding highlights the large potential costs that these density restrictions may be having on the London property market. We estimate that if the Blitz had not occurred, the resulting increase in density frictions in present day Greater London would cause total annual office rent revenues to fall by about £4.5 billion – equivalent to 1.2% of London's GDP or 39% of its average annual growth rate, so the effects are substantial. It is with great discretion that one should attempt to cast the deliberate bombing of civilians in a positive light. However the results of this study do beg the distressing question: Did the Luftwaffe brave the channel crossing and hostile fire only to rain down future lucre on 'lucky' London landowners? Thanks to what might be viewed as the British planning system's modern war on development, the answer indeed seems to be yes.

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Online Appendix

A.1 Other descriptive statistics

We report the descriptive statistics for the dataset on bombs in Table A1. The average distance to the River Thames is 5.3 km. If bombs would have fallen randomly, the average distance to the Thames would be 8 km: areas close to the Thames seem to have been bombed more heavily. Also the share of bombs that fell in conservation areas seem to be higher (22% versus 13%), but this is likely due to the fact that a greater proportion of Inner London has been preserved. Furthermore, areas close to infrastructure seem to have received more bombs. This may also reflect the fact that it was easier to construct new stations or highways on bombed sites.

In Figure A1 we plot bombed sites for the City of London and the Docklands. It can be seen that the location of bombs seems to be as good as random, taking into account that bombings usually occur in sequence, because airplanes flew in formation at specific speeds, in a certain direction, and dropped multiple bombs in succession. Figure A2 shows the population density in 1931. There is a strong positive correlation with agglomeration ($\rho = 0.748$), but population seems to be more spread than current employment and more heavily concentrated on the south bank of the River Thames.

In Table A2 we report descriptive statistics for all variables included in the rental dataset. Properties are often close to a highway (30% are within 500 m of a highway), which is similar to the share of observations within 500 m to a tube station or railway station (respectively 24% and 23%). Most of the properties are in, or close to, a conservation area (66% within 500 m). This is not too surprising as 37% of the total area in Inner London is part of a conservation area.

A.2 Bombs and refusal rates

As a first measure for density frictions, we use the refusal rate of office developments in Greater London, which we obtain from the Planning Statistics group at the Department for Communities and Local Government. The refusal rate as a measure of regulatory restrictiveness is used earlier by Bertrand & Kramarz (2002), Hilber & Vermeulen (2016) and Cheshire et al. (2018), among others. We sum the total number of applications for office developments in each borough between 1997 and 2008 and then calculate the share of refused projects. As an alternative proxy for

Table A1 – Descriptive statistics for the bomb census

	(1) mean	(2) sd	(3) min	(4) max
Distance to river Thames *(in km)*	5.299	4.592	0	21.99
In park,	0.0538	0.226	0	1
Park, 1-125m	0.107	0.309	0	1
Park, 125-250m	0.0813	0.273	0	1
Park, 250-500m	0.103	0.303	0	1
In large park	0.0405	0.197	0	1
Large park, 1-125m	0.0276	0.164	0	1
Large park, 125-250m	0.0311	0.174	0	1
Large park, 250-500m	0.0758	0.265	0	1
In water	0.0133	0.114	0	1
Water, 1-125m	0.193	0.394	0	1
Water, 125-250m	0.201	0.401	0	1
Water, 250-500m	0.333	0.471	0	1
Highway, $<$ 125m	0.0980	0.297	0	1
Highway, 125-250m	0.0787	0.269	0	1
Highway, 250-500m	0.133	0.339	0	1
Tube station, $<$ 125m	0.0252	0.157	0	1
Tube station, 125-250m	0.0601	0.238	0	1
Tube station, 250-500m	0.157	0.363	0	1
Railway station, $<$ 125m	0.0175	0.131	0	1
Railway station, 125-250	0.0476	0.213	0	1
Railway station, 250-500m	0.161	0.367	0	1
In conservation area	0.221	0.415	0	1
Conservation area, 1-125m	0.186	0.389	0	1
Conservation area, 125-250m	0.105	0.307	0	1
Conservation area, 250-500m	0.145	0.352	0	1
Listed buildings, $<$ 125m	1.542	4.601	0	85
Listed buildings, 125-250m	6.165	15.27	0	199
Listed buildings, 250-500m	24.69	52.88	0	484
Average household size	2.338	0.441	1.130	4.860
Share young people *($<$ 18)*	0.211	0.0814	0	0.550
Share elderly people *($\geq$ 65)*	0.129	0.0744	0	0.793
Share (re)married people	0.412	0.141	0.00493	0.821
Share foreigner (born elsewhere)	0.261	0.136	0.00906	0.806
Share unemployed	0.0434	0.0270	0	0.247
Share people in skilled occupation	0.0752	0.0427	0	0.288
Share high education *(level 4/5)*	0.320	0.166	0	0.805
Share owner-occupied housing	0.554	0.269	0	1
Share council housing	0.261	0.256	0	0.977

Note: The number of observations is 28,324

Figure A1 – Bombings in the City of London and the Docklands

Table A2 – Full descriptive statistics for rental dataset

	(1) mean	(2) sd	(3) min	(4) max
Rent *(in £ per m^2)*	384.8	179.4	10.76	1,507
Bomb density, $B(x)$, $\delta = 1.5$	215.0	43.52	0.124	269.2
Building site hit by bomb	0.0709	0.257	0	1
Agglomeration, d=150/10	130,400	47,559	695.9	198,939
Distance to river Thames *(in km)*	1.320	1.291	0.00497	17.42
Highway, < 125m	0.149	0.356	0	1
Highway, 125-250m	0.0945	0.293	0	1
Highway, 250-500m	0.169	0.375	0	1
Tube station, < 125m	0.131	0.338	0	1
Tube station, 125-250m	0.301	0.459	0	1
Tube station, 250-500m	0.483	0.500	0	1
Railway station, < 125m	0.0393	0.194	0	1
Railway station, 125-250m	0.118	0.322	0	1
Railway station, 250-500m	0.255	0.436	0	1
Park, < 125m	0.457	0.498	0	1
Park, 125-250m	0.389	0.487	0	1
Park, 250-500m	0.131	0.338	0	1
Large park, < 125m	0.0455	0.208	0	1
Large park, 125-250m	0.0717	0.258	0	1
Large park, 250-500m	0.126	0.332	0	1
Water, < 125m	0.145	0.353	0	1
Water, 125-250m	0.262	0.440	0	1
Water, 250-500m	0.429	0.495	0	1
In conservation area	0.676	0.468	0	1
Conservation area, 1-125m	0.265	0.441	0	1
Conservation area, 125-250m	0.0310	0.173	0	1
Conservation area, 250-500m	0.0183	0.134	0	1
Listed buildings, < 125m	13.66	11.34	0	67
Listed buildings, 125-250m	54.51	36.31	0	190
Listed buildings, 250-500m	208.1	119.2	0	480
Size of the property *(in m^2)*	847.7	2,445	17.19	65,032
Building size *(in m^2)*	6,256	11,813	40.41	112,305
Number of floors in building	7.970	5.155	1	52
Floor of property	3.352	2.768	0	50
Building – newly constructed	0.0898	0.286	0	1
Building – refurbished	0.0916	0.288	0	1
Building – second hand	0.824	0.381	0	1
Construction/refurbishment year < 1950	0.237	0.425	0	1
Construction/refurbishment year 1950-1959	0.0327	0.178	0	1
Construction/refurbishment year 1960-1969	0.0421	0.201	0	1
Construction/refurbishment year 1970-1979	0.0418	0.200	0	1
Construction/refurbishment year 1980-1989	0.137	0.343	0	1
Construction/refurbishment year 1990-1999	0.215	0.411	0	1
Construction/refurbishment year > 2000	0.294	0.456	0	1
Average household size	1.752	0.335	1.150	4.610
Share young people *(< 18)*	0.0918	0.0741	0	0.496
Share elderly people *($\geq$ 65)*	0.103	0.0641	0	0.552
Share (re)married people	0.289	0.0910	0.0484	0.646
Share foreigner (born elsewhere)	0.393	0.100	0.0459	0.713
Share unemployed	0.0413	0.0280	0	0.247
Share people in skilled occupation	0.0302	0.0295	0	0.159
Share high education *(level 4/5)*	0.515	0.128	0.0836	0.831
Share owner-occupied housing	0.299	0.134	0	0.939
Share council housing	0.213	0.214	0	0.915

Note: The number of observations is 9,202

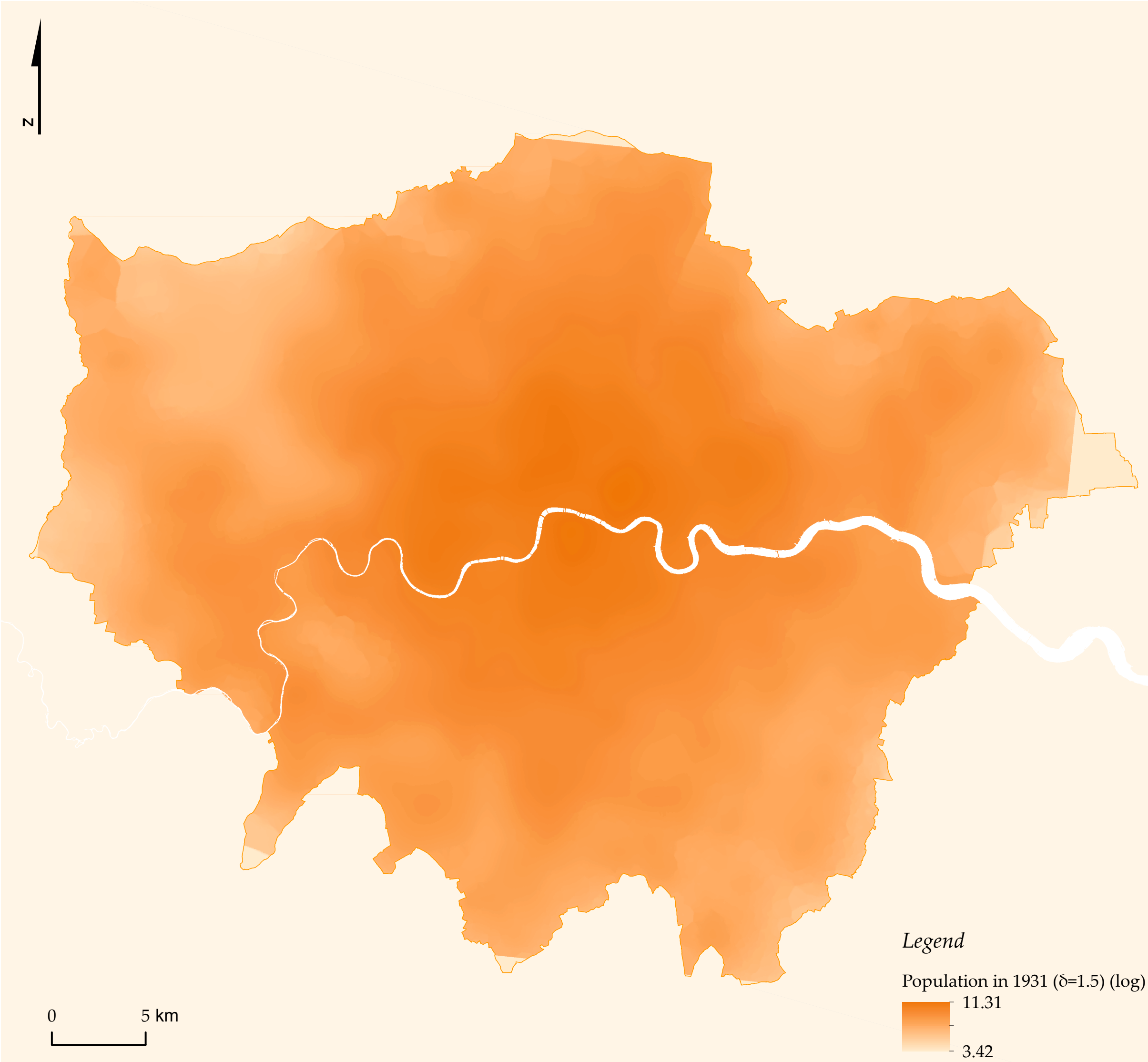


FIGURE A2 – POPULATION DENSITY IN 1931

Notes: We calculate population density as $\delta \int_0^Z e^{-\delta d(x,z)} pop(z) \mathrm{d}z$, where $pop(z)$ is the number of people at location z, $d(x,z)$ is the distance in km between x and z and δ is the decay parameter, which we set to 1.5.

density frictions, we use the share of office developments that only received a decision after 13 weeks or more, which we refer to as the delay rate.

Figure A3 reports the bivariate correlation between the bombs per km^2 and the refusal rate of office developments. As expected, there is a strong negative correlation ($\rho = -0.599$): regulatory constraints seem to be less restrictive when the bombs density is higher. One may argue that this is an underestimate if peripheral boroughs near the no-development greenbelt, where fewer bombs fell, may have been even more restrictive than more central locations. However, the correlation is almost identical if we only include local authorities within Inner London ($\rho = -0.615$).

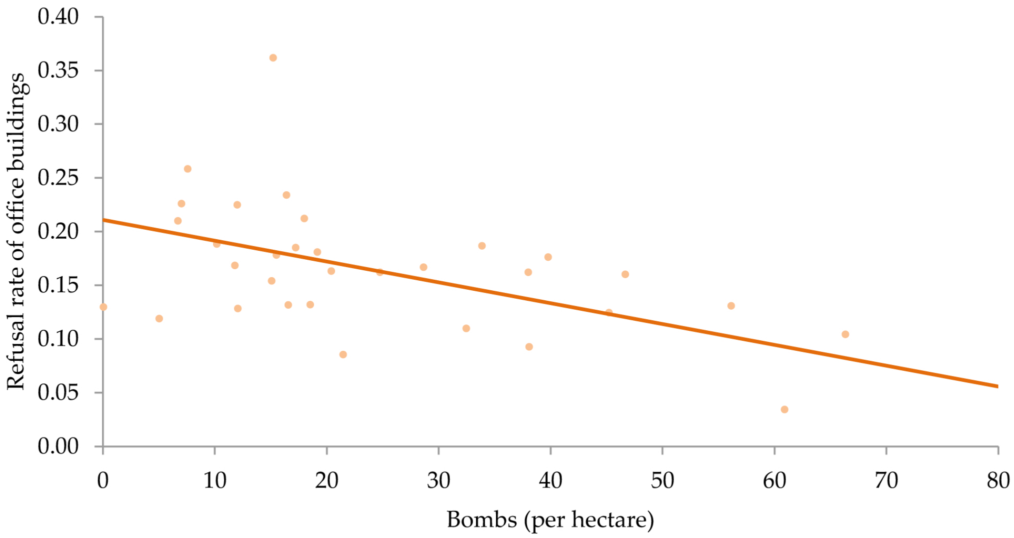


Figure A3 – Refusal rate of office developments in local authorities

As an alternative proxy for regulatory restrictiveness we use the delay rate. Figure A4 confirms the negative association between regulatory restrictiveness and bombs. The correlation between bomb density and the delay rate is lower ($\rho = -0.281$) but still is significant. For Inner London the correlation is $\rho = -0.205$.

Of course, these suggestive figures cannot be interpreted as a causal effect of the bombings on density frictions, simply because, from the perspective of Greater London, the bombings were not random and were mainly targeted at Inner London. Ideally, one should control for the distance to the Thames and the population in 1931, among other things. However, these analyses are not feasible because of the low number of observations (33 boroughs). It is therefore preferable, as we have done, to use bombings as a proxy for local density frictions and to exploit (local) spatial variation in density frictions using bomb densities.

A.3 Building height and bombings

Using the Points-of-Interest data we identify office buildings by selecting buildings that are occupied by commercial services.[32] The Points-of-Interest data classify four million places and real-world features in Great Britain by their use and function, also providing their postal address

[32] Commercial services include construction services; consultancies; employment and career agencies; engineering services; contract services; IT, advertising, marketing and media services; legal and financial services; personal, consumer and other services; property and development services; recycling services; repair servicing; research and design; transport, storage and delivery; and hire services.

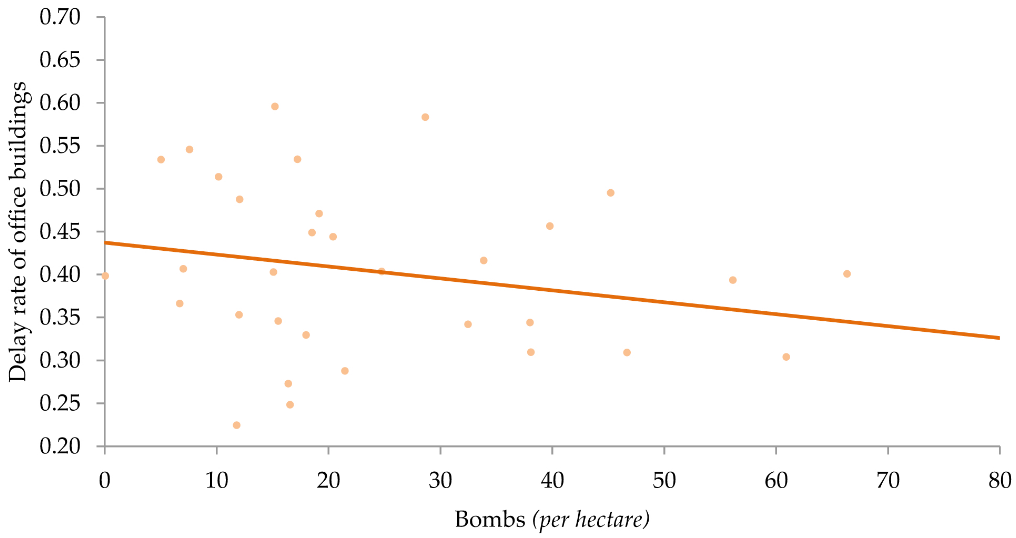


Figure A4 – Delay rate of office developments in local authorities

or location. We use the information on the postcode location of the building to link the building data to location attributes. We exclude observations for which the (maximum) building height is missing or lower than 5 m, which refers to about 1.5% of the data. Buildings with a footprint smaller than 25 m^2 are excluded. We end up with information on $2,164,940$ buildings, of which we classify $65,125$ buildings as offices. We also gather data on geographic attributes, such as the distance to a park, open water, the Thames, as well as location attributes such as the distance to; highways, railway stations, tube stations, and the nearest conservation area. Finally, we gather data on demographic attributes based on the 2001 Census at the Output Area level. Further, we calculate bomb density as per equation (7).

We report key descriptive statistics in Table A3. The average building height is about 10 m (about 3 floors) and the average footprint is 93 m^2. For an office building the footprint is almost 300 m^2. 0.3% of the building sites were directly hit by a bomb in the Blitz. Note that for Inner London the percentage is higher (0.5%).

We repeat the same set of specifications as in Section 3.3 for all buildings that have not been classified as offices. In Table A4 we find that again there are meaningful external and internal effects of bombings. However, the coefficients are somewhat smaller. This is not too surprising as it is mainly office buildings in London which are tall, implying that density frictions are most pronounced for them. The coefficient in column (6) implies that other buildings are 3.1% taller

Table A3 – Key descriptive statistics of the building sample

	(1) mean	(2) sd	(3) min	(4) max
Building height *(in m)*	9.959	3.680	5	304.2
Bomb density, $B(x)$, $\delta = 1.5$	59.44	46.01	0.00119	272.7
Building site hit by bomb, $b(x)$	0.00252	0.0501	0	1
Office building	0.0301	0.171	0	1
Footprint *(in m^2)*	92.71	360.1	25.00	187,106
Listed building	0.00660	0.0810	0	1
Distance to river Thames *(in km)*	6.717	4.473	0.000616	22.12
In conservation area	0.139	0.346	0	1

Note: The number of observations is 2,164,940

Table A4 – Bombings and building height

(Dependent variable: the log of building height in m)

	(1) (1) OLS	(2) (2) OLS	(3) (3) OLS	(4) (4) OLS	(5) (5) OLS	(6) (6) OLS
Bomb density, $B(x)$, $\delta = 1.5$ *(std)*	0.0885***	0.0652***	0.0493***	0.0387***	0.0339***	0.0306***
	(0.0002)	(0.0003)	(0.0005)	(0.0006)	(0.0006)	(0.0006)
Building site hit by bomb, $b(x)$	0.0136***	0.0172***	0.0248***	0.0260***	0.0270***	0.0296***
	(0.0050)	(0.0049)	(0.0047)	(0.0046)	(0.0046)	(0.0046)
Building – footprint *(log)*	0.1491***	0.1447***	0.1348***	0.1323***	0.1300***	0.1258***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Building – listed	0.1761***	0.1501***	0.0989***	0.0935***	0.0852***	0.0873***
	(0.0027)	(0.0027)	(0.0026)	(0.0026)	(0.0026)	(0.0026)
Geographical attributes (10)	No	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	No	No	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	No	Yes	Yes	Yes
Location attributes (10)	No	No	No	No	Yes	Yes
Demographic attributes (10)	No	No	No	No	No	Yes
Number of observations	2,099,815	2,099,815	2,099,815	2,099,815	2,099,815	2,099,8151
R^2	0.2531	0.2705	0.3592	0.3721	0.3755	0.3853

Notes: Bomb density is standardised *(std)* to have mean zero and unit standard deviation. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

when bomb density increases by one standard deviation. Furthermore, buildings that have been hit directly by bombs are 3.0% taller. Hence, as expected, the effects are more pronounced for office buildings.

A.4 CLMs and concentration of bombings

In Table A5 we report the main results for the conditional logit models (CLMs) that we use to predict the probability that a location is bombed. The column numbers refer to the corresponding columns in Table 1.

Table A5 – Conditional logit models of the probability to be bombed

(Dependent variable: location hit by bomb)

	(3) CLM	(4) CLM	(5) CLM	(6) CLM	(7) CLM
Distance to Thames *(in km)*	-0.3135***	-0.2060***	-0.1033***	-0.0985***	-0.0926***
	(0.0048)	(0.0071)	(0.0098)	(0.0099)	(0.0102)
In the Thames	-0.4303***	-0.7738***	-0.9535***	-0.9436***	-0.9490***
	(0.1175)	(0.1179)	(0.1202)	(0.1203)	(0.1204)
In park	1.0862***	0.5449***	0.3371***	0.3347***	0.3355***
	(0.0534)	(0.0557)	(0.0593)	(0.0596)	(0.0596)
Park 1-125m	1.0061***	0.3587***	0.1394***	0.1224***	0.1205***
	(0.0242)	(0.0292)	(0.0349)	(0.0353)	(0.0353)
Park 125-250m	0.8621***	0.3097***	0.1343***	0.1155***	0.1087***
	(0.0278)	(0.0307)	(0.0350)	(0.0352)	(0.0352)
Park 250-500m	0.5764***	0.1982***	0.1334***	0.1394***	0.1350***
	(0.0273)	(0.0286)	(0.0304)	(0.0305)	(0.0306)
In large park	-0.7691***	-0.3986***	-0.3612***	-0.3374***	-0.3365***
	(0.0601)	(0.0623)	(0.0652)	(0.0654)	(0.0656)
Large park 1-125m	-0.5558***	-0.2212***	-0.1566***	-0.1494***	-0.1410***
	(0.0419)	(0.0437)	(0.0470)	(0.0472)	(0.0473)
Large park 125-250m	-0.4595***	-0.2080***	-0.1711***	-0.1672***	-0.1563***
	(0.0412)	(0.0420)	(0.0445)	(0.0446)	(0.0447)
Large park 250-500m	-0.2211***	-0.1156***	-0.1430***	-0.1484***	-0.1406***
	(0.0303)	(0.0311)	(0.0329)	(0.0328)	(0.0330)
In water	-1.4592***	-1.1073***	-0.9279***	-0.9048***	-0.9030***
	(0.0638)	(0.0643)	(0.0645)	(0.0645)	(0.0644)
Water 1-125m	-0.5093***	-0.2281***	-0.1987***	-0.1911***	-0.1904***
	(0.0188)	(0.0196)	(0.0201)	(0.0201)	(0.0202)
Water 125-205m	-0.6823***	-0.3832***	-0.2552***	-0.2523***	-0.2509***
	(0.0178)	(0.0190)	(0.0193)	(0.0193)	(0.0193)
Water 250-500m	-0.1259***	-0.0232	-0.0473***	-0.0478***	-0.0474***
	(0.0157)	(0.0160)	(0.0164)	(0.0164)	(0.0164)
Borough fixed effects (33)	No	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	Yes	Yes	Yes
Location attributes (13)	No	No	No	Yes	Yes
Demographic attributes (10)	No	No	No	No	Yes
Number of observations	7,081,000	7,081,000	7,081,000	7,081,000	7,081,000
Log-likelihood	-150,134	-145,448	-143,558	-143,483	-143,456

Notes: The number of observations is the number of bombs times the number of sampled alternatives ($28,324 \times 250$). Column numbers refer to the different estimates of the concentration index in Table 1. Standard errors are in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

In column (3) we show that indeed the bomb density tends to be higher close to the Thames; when moving further away the probability to be bombed becomes lower. However, the number of bombs that fell in the Thames is unexpectedly low, probability due to recording errors. The probability that a location close to a park or garden is bombed tends to be higher, possibly because of the presence of Barrage Balloons which were often tethered near open spaces. On the other hand, parks that are larger than 10 ha (*e.g.* Richmond Park, Greenwich Park) attracted fewer bombs, likely again because of recording issues. Similarly, locations in and close to water bodies have received fewer bombs.

The results are very similar once we control for borough and *zielraum*×borough fixed effects in, respectively, columns (4) and (5). In column (6) we add 13 location attributes, for which the estimated coefficients are available upon request. It appears that the probability to have been bombed is a bit higher close to highways and tube stations. It might be that infrastructure developments were easier and cheaper to construct in areas that were bombed. We find no evidence of a relationship between bombings and the presence of historic amenities (not reported in Table A5), as it seems that no fewer bombs have fallen in locations that are now conservation areas. Because the *zielraum*×borough areas are small and are often almost fully part of a conservation area, it may be hard to identify those effects.

In the final column of Table A5 we add 10 neighbourhood attributes, leading to almost the same results. Areas that have been bombed now seem to host smaller and younger households, often immigrants, in line with preliminary evidence of Redding & Sturm (2016) which show that a higher share of war-time destruction is associated with a higher share of non-whites.

In Figure A5 we illustrate the estimated K-density and confidence bands of counterfactuals. We display the 95% confidence intervals for the unconditional counterfactual as the light dotted lines (see column (1), Table 1 and the conditional counterfactual with *zielraum*×borough fixed effects and geographic controls as the dark dotted lines (see column (5), Table 1). Only in the latter case, the estimated K-density (the dark line) falls entirely within the 95% confidence, confirming that bombings are conditionally random.

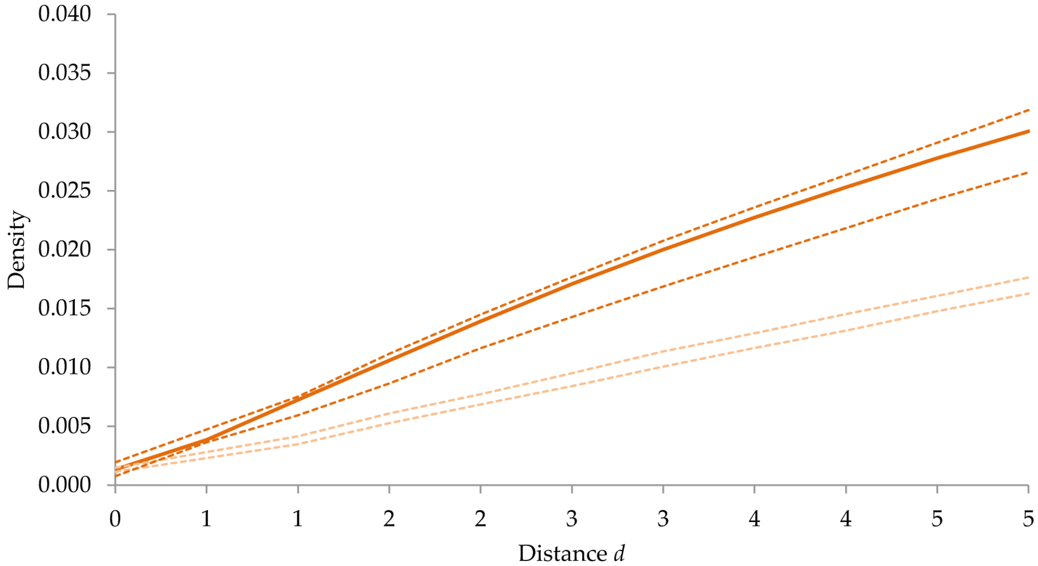


Figure A5 – K-density for bombings

Notes: The light dotted lines denote the 95% confidence bands for the unconditional counterfactual, while the dark dotted lined denote the 95% confidence bands with *zielraum*×borough fixed effects and geographic controls. The dark line represents the estimated K-density.

A.5 The decay parameter

In the paper, we calculate the spatially weighted density of bombs. One important parameter is the decay parameter δ, indicating how steep the decay function is. Figure A6 shows the weight of one bomb at different distances from a location for different decay parameters. For $\delta = 1.5$, the weight of a bomb that fell 1 km away is only 0.2231. For $\delta = 3$ the weight falls to 0.0498 and increases to 0.3716 for $\delta = 1$.

A.6 Clustering

One may be worried that the standard errors, which we cluster at the building level, are clustered at the wrong level. Clustering at the building level may be somewhat arbitrary, but there is no obvious preferred choice. Hence, showing that conclusions do not change when clustering at different levels is important. The first three columns in Table A6 repeat the preferred specification (column (6), Table 4) for density frictions. We show that when we cluster at higher levels, such as output areas, wards, or constituencies, the standard errors are a bit higher. However, in all specifications all coefficients remain statistically significant at the 1% level.

The same holds when we investigate the impact of agglomeration on rents (columns (4)-(6) in Table A6. The standard errors are again higher, but both the first-stage and second-stage

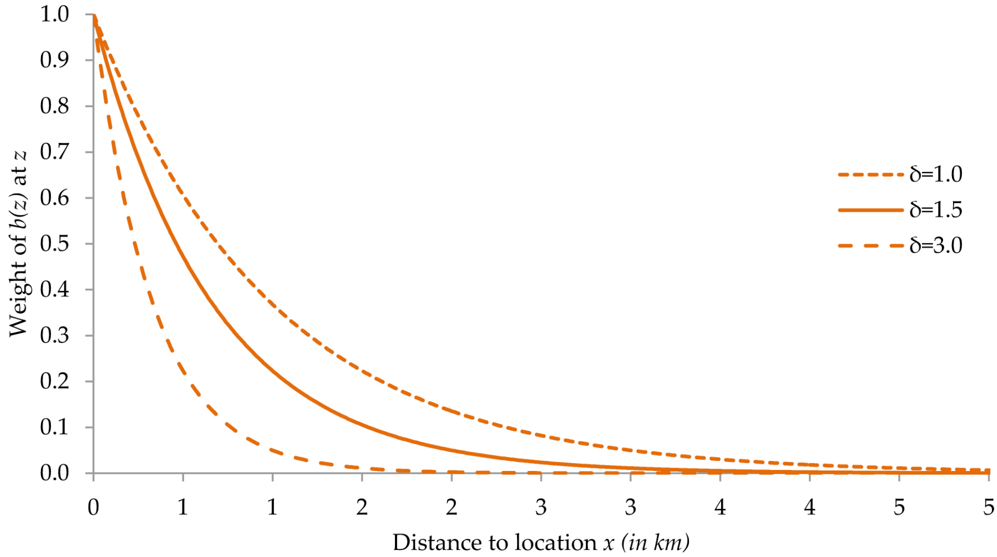


Figure A6 – Spatial weights for different δ

Table A6 – Sensitivity analysis: clustering

(Dependent variable: the log of rent per m^2)

	Output area	Ward	Constituency	Output area	Ward	Constituency
	(1) OLS	(2) OLS	(3) OLS	(4) 2SLS	(5) 2SLS	(6) 2SLS
Bomb density, $B(x)$, $\delta = 1.5$ *(std)*	0.0835***	0.0835***	0.0835**			
	(0.0205)	(0.0266)	(0.0358)			
Agglomeration, $A(x)$, $\delta = 1.5$, *(log)*				**0.2873*****	**0.2873*****	**0.2873****
				(**0.0678**)	(**0.0917**)	(**0.1376**)
Building attributes (14)	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	Yes	Yes	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	Yes	Yes	Yes	Yes	Yes	Yes
Location attributes (13)	Yes	Yes	Yes	Yes	Yes	Yes
Demographic attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	9,202	9,202	9,202	9,202	9,202	9,202
R^2	0.5966	0.5966	0.5996			
Kleibergen-Paap F-statistic				125.6	50.93	46.91

Notes: **Bold** indicates instrumented. Bomb density is standardised *(std)* to have mean zero and unit standard deviation. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

Table A7 – First-stage results: bombing and agglomeration

(Dependent variable: the log of agglomeration, $A(x)$, $\delta = 1.5$)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
Bomb density, $B(x)$, $\delta = 1.5$ *(std)*	0.5495***	0.5327***	0.4023***	0.3749***	0.3100***	0.2908***
	(0.0096)	(0.0105)	(0.0175)	(0.0182)	(0.0193)	(0.0187)
Building site hit by bomb, $b(x)$	-0.0740**	-0.0269	-0.0314	-0.0069	-0.0048	0.0010
	(0.0371)	(0.0284)	(0.0302)	(0.0203)	(0.0177)	(0.0167)
Number of observations	9,202	9,202	9,202	9,202	9,202	9,202
R^2	0.7468	0.8072	0.8850	0.9306	0.9503	0.9550

Note: Bomb density is standardised *(std)* to have mean zero and unit standard deviation. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

coefficients remain highly statistically significant.

A.7 First-stage estimates

In Panel B of Table 5 we instrument agglomeration economies with bomb density. Here, we make sure that the instrument has the expected positive effect. In Table A7 we report first-stage estimates. The coefficient in column (1) implies that 1% increase in bomb density seems to translate into a 0.55% increase in agglomeration. However, because bombings are not random, this coefficient may be biased. Indeed, the elasticity reduces to 0.37 when adding geographic controls and *zielraum*×borough fixed effects in column (4). When including more location variables (column (5)) and demographic variables (column (6)), the elasticity is reduced to about 0.3.

A.8 Sensitivity analysis for for density frictions

Table A8 summarizes the results for density frictions. We first test whether the *net* internal effect of a building site being bombed has any significance. If we exclude all building attributes in column (1), it is shown that the dummy indicating whether the building site is bombed is not statistically significant and close to zero, while the bomb density effect is positive and significant. This suggests that the 'reduced-form' internal effect – that pre-war buildings are less efficient or offer a different quality – does not seem to be relevant for office tenants, while the external effect of density frictions is still very important. This result further supports our contention that, in London, regulatory density frictions significantly reduce agglomeration economies, whereas other potential forms of density frictions (*e.g.* the inefficiency of historic buildings) are less salient.

Table A8 – Sensitivity analysis: density frictions

(Dependent variable: the log of rent per m^2)

	Internal effect	Firm sorting	Exact bombs	1931 population	Control for Thames	Only Inner London	No City of London	> 1km of Zielraums	Neighbourhood constr. year	Constituency fixed effects	1931 Parish fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Bomb density, $B(x)$, $\delta = 1.5$ *(std)*	0.0680***	0.1056***	0.0835***	0.0866***	0.1047***	0.0780***	0.0737***	0.0588**	0.0979***	0.0714***	0.1336***
	(0.0196)	(0.0314)	(0.0171)	(0.0171)	(0.0235)	(0.0173)	(0.0184)	(0.0270)	(0.0175)	(0.0147)	(0.0213)
Building site hit by bomb, $b(x)$	-0.0045	-0.0260	-0.0369	-0.0377*	-0.0369	-0.0366	-0.0437	-0.0481	-0.0378*	-0.0442*	-0.0417*
	(0.0275)	(0.0346)	(0.0227)	(0.0228)	(0.0224)	(0.0228)	(0.0281)	(0.0396)	(0.0224)	(0.0234)	(0.0237)
Population 1931, $\delta = 1.5$, *(log)*				0.1519*							
				(0.0842)							
River Thames < 500m					0.0168						
					(0.0565)						
River Thames $500 - 1000$m					-0.0152						
					(0.0518)						
River Thames $1000 - 1500$m					0.0390						
					(0.0470)						
River Thames $1500 - 2000$m					0.1012**						
					(0.0408)						
River Thames $2000 - 2500$m					0.1432***						
					(0.0353)						
Mean construction year									-0.0187***		
year $\div 10$, $\delta = 1.5$									(0.0037)		
Building attributes (14)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Firm fixed effects (1,102)	No	Yes	No	No	No	No	No	No	No	No	No
Constituency fixed effects (73)	No	No	No	No	No	No	No	No	No	Yes	No
Parish 1931 fixed effects (188)	No	No	No	No	No	No	No	No	No	No	Yes
Number of Observations	9,196	9,196	9,196	9,196	9,196	8,941	7,397	4,765	9,196	9,196	9,196
R^2	0.4870	0.8497	0.5966	0.5970	0.6018	0.5742	0.6246	0.6396	0.6008	0.5812	0.5896

Notes: Bomb density is standardised *(std)* to have mean zero and unit standard deviation. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

One might argue that our result may be caused by firm sorting; productive firms of a certain kind sort themselves to the densest areas. Moreover, it is not unlikely that the latter type of firm offers higher wages, so that our measures of an external and internal effect of density frictions also contains a wage effect (see Section 2). To address this issue we include 1,102 firm fixed effects, thereby comparing the rents paid by identical firms within *zielraum*×borough areas. It seems very unlikely that the same firm within a small area pays different wages. Column (2) shows that the wage effect is unlikely to be important: a standard deviation increase in bomb density increases rents by 10.6%. This estimate is not statistically significantly different from the baseline estimate.

In column (3), Table A8 we remove all bombs for which the locations were marked as 'unsure' and we omit parachute mines, which could have devastating effects, but on the other hand quite often did not detonate. This removes about 2% of the bombs and should eliminate some measurement error associated with bomb density. However, the estimates are essentially the same compared to the baseline estimates.

Because the goal was to demoralize the population, it may be expected that the Germans specifically targeted dense areas. To the extent *zielraum*×bourough fixed effects do not control for this, controlling for the pre-war population density may be important. We therefore gather data on population counts in 1931 at the Parish level. However, the coefficient is hardly affected by this exercise. Nevertheless, locations which had a higher population density in 1931 tend to command somewhat higher rents nowadays. We also make sure that this result still holds if we include a third-order polynomial of population density in 1931.[33]

In the baseline analysis we control for the log distance to the Thames, because the Germans may have used it to navigate. However, one may argue that using only the log is too contrived. In column (5) we therefore flexibly control for the distance to the River Thames by including 500 m distance band dummies. The results indicate that the coefficient of bomb density is similar, albeit slightly higher (the coefficient is now 0.1047).

In column (6) of Table A8 we only include observations in Inner London, which removes a small portion of the observations but leaves the results unchanged. The City of London was heavily

[33] Results are available upon request.

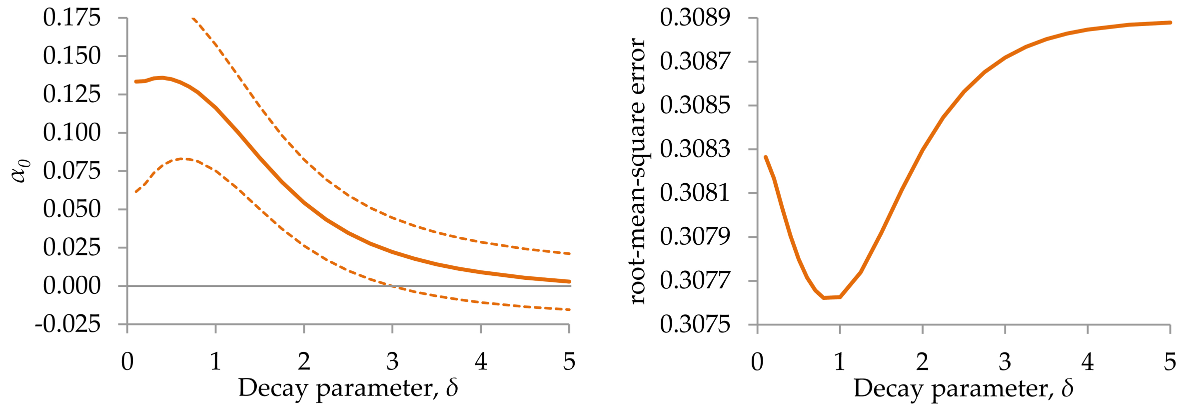
bombed during the Blitz, but has been a significant business center for centuries. One might therefore be worried that the effect we measure is mainly driven by density frictions in the City of London. However, in column (7) if we exclude all transactions in the City of London (20% of the total) the results are similar.

Furthermore, it may have been the case that the Germans were able to successfully focus attacks on some specific targets. We therefore exclude all observations inside and within 1 km of a *zielraum*. Because most of our observations are within this distance, we only keep about 50% of the data. However, as shown in column (8) the coefficient of bomb density is similar, suggesting that a standard deviation increase in bomb density leads to a rent increase of 5.9%.

One may argue that the positive external effect we found in the office market is mainly attributable to the fact that building quality is higher in bombed areas, where bombed pre-war buildings have been replaced by newer buildings of higher quality. These buildings might have positive (external) effects on surrounding properties. We therefore calculate the average year of construction or latest refurbishment based on office transactions using a decay function identical to equation (7). Column (9) shows that there seems a negative effect of the average age of surrounding buildings on office rents. This may be because historic buildings offer more aesthetic benefits. More importantly, the effect of bomb density remains similar to the baseline specification. Although not reported, we also find that this result also holds if we include third-order polynomials of the mean construction/refurbishment year of offices.

In the final two columns of Table A8 we investigate whether the choice to include *zielraum*×bourough fixed effects matter for our results. In principle, the geographic level of the fixed effects should not be too small as then the fixed effects will absorb any identifying variation, while if the fixed effects are too large, bombings may not be conditionally random. As a first alternative we use parliamentary constituency fixed effects. There are 73 parliamentary constituencies in Greater London of which the median size is 18.35 km^2. In column (10) it is shown that the effect of bomb density on rents is similar. Alternatively, we may also include 1931 Parish fixed effects, which tend to be a bit smaller than parliamentary constituencies, but are often oddly shaped.[34] The results indicate that the effect of bomb density becomes stronger once

[34] Grays Inn, Lincolns Inn and Inner Temple are for example Parishes that are smaller than 0.1 km^2, while Croydon Saint John the Baptist is more than 50 km^2.



(A) Estimated parameters (B) Root-mean-squared error

Figure A7 – The choice of the decay parameter δ for density frictions

including more detailed fixed effects: the coefficient implies that a standard deviation increase in bomb density leads to a rent increase of 13.4%.

As a final check we investigate how the results change if we vary the decay parameter for bomb density δ. In Panel A of Figure A7 we show that the impact of bomb density on rents (α_0) is statistically significant as long as $\delta < 3$. Hence, the external effect is not an extremely local phenomenon, in line with the idea that the importance of agglomeration economies reach further than the own street or block. In Panel B of Figure A7 we plot the root-mean-square error for α_0, showing that this is minimzsed for $\delta \approx 1$, which is reasonably close to $\delta = 1.5$. Hence, $\delta = 1.5$ seems a sensible choice, in particular because differences in the root-mean-squared error are minor.

Hence, the results confirm an economically and statistically significant effect of bomb density on rents in all specifications.

A.9 Sensitivity analysis for agglomeration economies

We now test the robustness of the impact of agglomeration on office rents. The results of the various sensitivity analyses are reported in Table A9.[35]

Although we define agglomeration as employment density, in column (1) we investigate whether the use of a different proxy matters for our result. Using information on building-use type from the Points of Interest data, and building heights and footprints from the Ordnance Survey, we

[35] We focus on 2SLS estimates. The OLS estimates are very similar and available upon request.

Table A9 – Sensitivity analysis: agglomeration economies

(Dependent variable: the log of rent per m^2)

	Building volume	Firm sorting	Exact bombs	1931 population	Control for Thames	Only Inner London	No City of London	> 1km of Zielraums	Neighbourhood constr. year	Constituency fixed effects	1931 Parish fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
Agglomeration, $A(x)$, $\delta = 1.5$, *(log)*		**0.3390*****	**0.2873*****	**0.2852*****	**0.4563*****	**0.2739*****	**0.2555*****	**0.1908****	**0.3263*****	**0.1988*****	**0.3646*****
		(**0.1063**)	(**0.0579**)	(**0.0555**)	(**0.1070**)	(**0.0602**)	(**0.0615**)	(**0.0856**)	(**0.0594**)	(**0.0392**)	(**0.0564**)
Office building agglomeration,	**0.3249*****										
$A(x)$, $\delta = 1.5$, *(log)*	(**0.0655**)										
Population 1931, $\delta = 1.5$, *(log)*				-0.0297							
				(0.0856)							
River Thames < 500m					-0.0773						
					(0.0734)						
River Thames 500-1000m					-0.1238*						
					(0.0724)						
River Thames 1000-1500m					-0.0935						
					(0.0715)						
River Thames 1500-2000m					-0.0307						
					(0.0648)						
River Thames 2000-2500m					0.0156						
					(0.0537)						
Mean construction year									-0.0147***		
year $\div 10$, $\delta = 1.5$									(0.0035)		
Building attributes (14)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic attributes (10)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Zielraum$\times$borough fixed effects (232)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Firm fixed effects (1,102)	No	Yes	No	No	No	No	No	No	No	No	No
Constituency fixed effects (73)	No	No	No	No	No	No	No	No	No	Yes	No
Parish 1931 fixed effects (188)	No	No	No	No	No	No	No	No	No	No	Yes
Number of Observations	9,196	9,196	9,196	9,196	9,196	8,941	7,397	4,765	9,196	9,196	9,196
Kleibergen-Paap F-statistic	184.3	60.29	241.8	325.3	150.9	233.3	233	143.3	273.6	408	277.7

Notes: **Bold** indicates instrumented. Standard errors are clustered at the building level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

estimate each building's volume and then calculate weighted building volume in the spirit of equation (10). The estimated elasticity is remarkably close to the baseline estimate, suggesting that both employment density as well as office building volume are valid proxies for agglomeration economies.

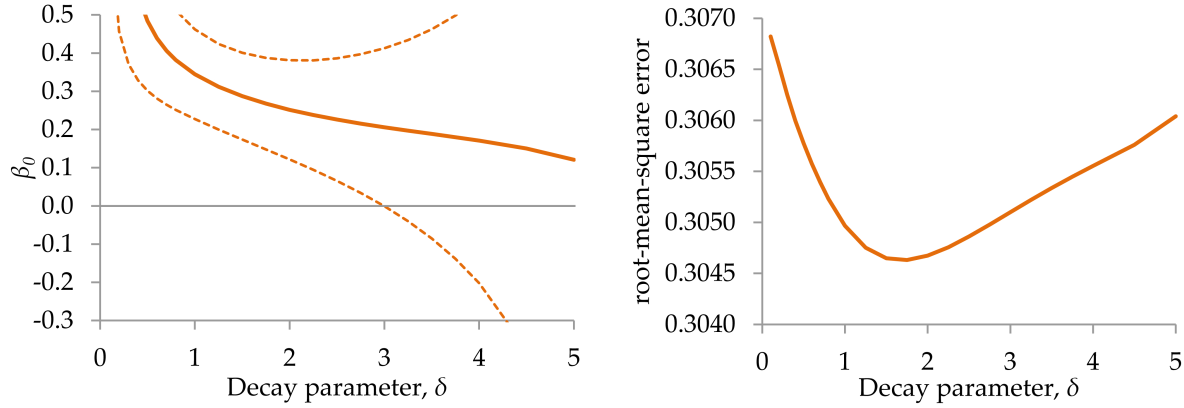
Column (2) addresses the issue of firm sorting and inter-firm wage differences by including $1,102$ firm fixed effects. The elasticity is then virtually identical to the baseline estimate.

When we only take into account bombs for which we know the exact location and exclude parachute mines in column (3), the coefficient is very similar again to the baseline estimate. Column (4) shows that also controlling for population density in 1931 does not change the result. In column (5) in Table A9 we flexibly control for the distance to the Thames. This leads to a somewhat stronger estimate for agglomeration (the elasticity is 0.4563). When we only include observations in Inner London, exclude the City of London, or exclude observations inside or within 1 km of *zielraums* in columns (6), (7) and (8) respectively, the estimated effects are comparable to the baseline estimate. In column (9) we control for the average construction/refurbishment year in the neighbourhood. Column (10) and (11) investigate whether the inclusion of alternative fixed effects (*i.e.* constituency and Parishes from 1931) change the results. If anything, the coefficients tend to be somewhat stronger.

The final sensitivity analysis focuses on the choice of the decay parameter δ, which indicates how quickly effects of agglomeration economies dissipate. We plot the estimated coefficient related to density frictions (β_0) with respect to δ. It is shown in Panel A of Figure A8 that for $\delta < 3$, bomb density is significant at the 5% level. For very low levels of δ, we cannot sufficiently identify the effect, leading to unrealistically large estimates. In Panel B of Figure A8, the root-mean-squared error is minimized for $\delta \approx 1.75$, which is very close to the choice of $\delta = 1.5$.

A.10 Housing market analysis

If land uses are mixed in a city, office rents and house prices should be (strongly) positively correlated (Lucas & Rossi-Hansberg 2002, Koster & Rouwendal 2013). More specifically, Lucas & Rossi-Hansberg (2002) show that in a mixed area, households' bid rents should be identical to bid rents for firms and independent of commuting costs. This section investigates the extent



(A) Estimated parameters (B) Root-mean-squared error

Figure A8 – The choice of the decay parameter δ for agglomeration economies

to which the substitution of commercial rents for house prices is empirically valid. As most of London has mixed land use,[36] we might expect results using house prices to be similar to those using office rents.

For this analysis, we use data on house prices obtained from the Nationwide Building Society. The data provides information on 128,931 housing transactions, so the housing sample is substantially larger than the data on office rents and covers a much wider area of Greater London. In a recent working paper, Redding & Sturm (2016) provide preliminary evidence that house prices within 200 m of areas heavily damaged (and therefore bombed) by the Blitz may be lower, due to negative social interactions (*e.g.* in heavily damaged areas more public council housing may have been constructed). Because we do not have information on the exact location of each property (only postcode areas), we cannot replicate this level of detail. We therefore include a control variable measuring the number of bombs within 200 m of the postcode, which should have a negative effect on house prices.

In Table A10 we present the key descriptives for the housing sample. The average house price per m^2 is £2,343. The average size of a residential property is much smaller than an office at 91 m^2. It can also be seen that the distance to the River Thames is much higher than in the office rents or building height sample, which is in line with anecdotal evidence suggesting that residential properties are much less spatially concentrated than commercial properties. Because we have much more observations outside Inner London than in the office building sample, the

[36] As an illustration, in about 50% of the output areas, the ratio of jobs to households is larger than 0.25 and smaller than 2.5.

Table A10 – Key descriptives for housing sample

	(1) mean	(2) sd	(3) min	(4) max
House price *(in £ per m^2)*	2,343	1,185	259.1	10,000
Bomb density, $B(x)$, $\delta = 1.5$	58.35	43.14	5.93e-05	272.7
Bombs, $<$ 200m	3.010	0	36	
Agglomeration, $A(x)$, $\delta = 1.5$	8,768	12,175	95.08	190,502
Distance to Thames *(in km)*	7.531	4.507	0	20.46
In conservation area	0.139	0.346	0	1
House size *(in m^2)*	91.22	35.61	24	278
Flat	0.420	0.494	0	1
Construction year $<$ 1940	0.680	0.467	0	1
Construction year $\geq$ 2000	0.0333	0.180	0	1

Notes: The number of observations is 128,931.

share of properties that are in a conservation area is also much lower (only 13.9%).

We first focus on the results related to density frictions by estimating reduced-form regressions of house prices on bomb density. Table A11 reports these results. Column (1) shows that a standard deviation increase in bombings seems to imply a house price increase of 3%, which drastically changes once we control for geographic variables. However, these results are not reliable as bombings are not random when one does not include location fixed effects. In column (3) we include borough fixed effects. Then, we find that a standard deviation increase in bomb density raises rents by 3.4%. Furthermore in line with Redding & Sturm (2016), we find negative local effects of the number of bombs within 200 m. Per bomb, the price decrease is 0.5%. In heavily bombed areas this implies a strong price effect of up to 20%. Hence, given that we are able to replicate the result of Redding & Sturm (2016), it seems that results using actual bomb damage data or bomb strikes are similar, which supports the validity of using bomb strikes in our estimations. The effect of bomb density is similar once we include *zielraum*×borough fixed effects in column (4). The effect of nearby bombs is now 30% lower, but still highly statistically significant. The results are very similar once we include location and demographic attributes in, respectively, columns (5) and (6). One may argue that housing prices and office rents are hardly correlated in fully residential areas, so that the estimated coefficient of bomb density may not capture density frictions in residential areas. In the final column we therefore only keep properties in mixed areas, *i.e.* we keep properties in output areas where the ratio of employment to households is larger than one. It is shown that the estimated effect is now below but close to the baseline estimate for the office market: a standard deviation increase in bomb density

Table A11 – Reduced form results: density frictions and house prices

(Dependent variable: the log of house price per m^2)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS
Bomb density, $B(x)$, $\delta = 1.5$ *(std)*	0.0304***	-0.0610***	0.0340***	0.0297***	0.0206***	0.0354***	0.0616***
	(0.0019)	(0.0019)	(0.0025)	(0.0030)	(0.0029)	(0.0026)	(0.0057)
Bombs, < 200m	0.0136***	0.0121***	-0.0054***	-0.0038***	-0.0038***	-0.0029***	-0.0039***
	(0.0006)	(0.0006)	(0.0005)	(0.0005)	(0.0005)	(0.0004)	(0.0008)
House size *(log)*	-0.3613***	-0.3782***	-0.4157***	-0.4467***	-0.4567***	-0.5104***	-0.4870***
	(0.0054)	(0.0049)	(0.0041)	(0.0038)	(0.0037)	(0.0035)	(0.0074)
Number of bathrooms	0.0712***	0.0550***	0.0414***	0.0380***	0.0364***	0.0308***	0.0420***
	(0.0023)	(0.0021)	(0.0017)	(0.0016)	(0.0015)	(0.0014)	(0.0030)
Number of bedrooms	0.0547***	0.0580***	0.0610***	0.0656***	0.0682***	0.0727***	0.0719***
	(0.0020)	(0.0018)	(0.0015)	(0.0014)	(0.0014)	(0.0013)	(0.0028)
Private parking space	-0.0148***	0.0020	0.0457***	0.0493***	0.0473***	0.0397***	0.0446***
	(0.0025)	(0.0023)	(0.0019)	(0.0018)	(0.0017)	(0.0016)	(0.0032)
Garage	0.0549***	0.0628***	0.0538***	0.0500***	0.0504***	0.0305***	0.0213***
	(0.0026)	(0.0024)	(0.0020)	(0.0019)	(0.0018)	(0.0017)	(0.0036)
House type – detached	0.2468***	0.2674***	0.2507***	0.2317***	0.2255***	0.1798***	0.1672***
	(0.0048)	(0.0046)	(0.0041)	(0.0039)	(0.0038)	(0.0035)	(0.0081)
House type – semi-detached	0.0818***	0.0862***	0.0742***	0.0648***	0.0636***	0.0439***	0.0403***
	(0.0027)	(0.0025)	(0.0020)	(0.0019)	(0.0019)	(0.0016)	(0.0036)
House type – flat	0.0837***	0.0573***	-0.0353***	-0.0607***	-0.0703***	-0.0968***	-0.0831***
	(0.0033)	(0.0030)	(0.0024)	(0.0022)	(0.0022)	(0.0020)	(0.0041)
House type – maisonette	0.0698***	0.0439***	-0.0455***	-0.0689***	-0.0765***	-0.1015***	-0.0851***
	(0.0058)	(0.0053)	(0.0045)	(0.0043)	(0.0042)	(0.0038)	(0.0083)
Constuction year dummies (7)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	No	Yes	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	No	No	Yes	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	No	Yes	Yes	Yes	Yes
Location attributes (13)	No	No	No	No	Yes	Yes	Yes
Demographic attributes (10)	No	No	No	No	No	Yes	Yes
Number of observations	128,931	128,931	128,931	128,931	128,931	128,931	30,307
R^2	0.7022	0.7497	0.8309	0.8536	0.8592	0.8851	0.8893

Notes: Bomb density is standardised *(std)* to have mean zero and unit standard deviation. Standard errors are clustered at the postcode and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

increases house prices by 6.2%.

Second, we focus on the effect of agglomeration economies on house prices of which the second-stage results are reported in Table A12. The results in the first two columns are again unreliable, but once we include borough fixed effects we find an elasticity of 0.0732, which is also somewhat lower than the estimate for the office market. This is confirmed once we include *zielraum*×borough fixed effects in column (4) and add location attributes and demographic controls in columns (6) and (7), respectively. Again, the correlation between house prices and rents is expected to be higher in mixed areas. Hence, in column (7), we only keep observations in output areas that have an employment to household ratio of larger than one. The estimated coefficient implies that doubling agglomeration leads to a house price increase of 12.3%, which is less than half the estimated elasticity for the office market.

Table A12 – Results: agglomeration economies and house prices

(Dependent variable: the log of house price per m^2)

	(1) 2SLS	(2) 2SLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
Agglomeration, $A(x)$, $\delta = 1.5$, *(log)*	**0.0807*****	**-0.2439*****	**0.0732*****	**0.0788*****	**0.0566*****	**0.1024*****	**0.1778*****
	(**0.0046**)	(**0.0098**)	(**0.0053**)	(**0.0080**)	(**0.0081**)	(**0.0076**)	(**0.0170**)
Bombs, $<$ 200m	0.0118***	0.0162***	-0.0041***	-0.0029***	-0.0032***	-0.0021***	-0.0031***
	(0.0007)	(0.0009)	(0.0004)	(0.0005)	(0.0004)	(0.0004)	(0.0008)
Constuction year dummies (7)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects (15)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical attributes (10)	No	Yes	Yes	Yes	Yes	Yes	Yes
Borough fixed effects (33)	No	No	Yes	Yes	Yes	Yes	Yes
Zielraum×borough fixed effects (232)	No	No	No	Yes	Yes	Yes	Yes
Location attributes (13)	No	No	No	No	Yes	Yes	Yes
Demographic attributes (10)	No	No	No	No	No	Yes	Yes
Number of observations	128,931	128,931	128,931	128,931	128,931	128,931	30,307
Kleibergen-Paap F-statistic	8,575	4,124	9,544	6,702	6,140	5,943	1,676

Notes: **Bold** indicates instrumented. Standard errors are clustered at the postcode level and in parentheses; *** $p < 0.01$, ** $p < 0.5$, * $p < 0.10$.

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